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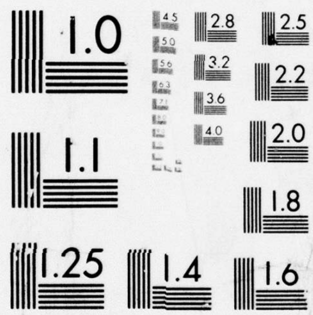

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6 AGARD Conference Proceedings No.190

RECENT EXPERIENCE/ADVANCES IN AVIATION PATHOLOGY

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Last page

Papers presented at the Aerospace Medical Panel Specialists' Meeting held in Copenhagen, Denmark, 5–9 April 1976.

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PREFACE

Application of the methods and techniques of pathology to the investigation of aircraft accidents and the solution of aeromedical problems is not new. As early as the beginning of the 20th century the pathologist was called upon to make determinations as to the cause and manner of death in fatal aircraft accidents.

As with any field that must adapt to changing times and ideas, the aviation pathologist has been faced with innovations and changing concepts. Problems arise concerning local, national, and international law in determining jurisdiction and other medicolegal questions. New and unique aircraft are added to the aerospace inventory each year. Specialized operational concepts are continually being developed that involve existing aircraft performing missions and maneuvers that stress the limits of performance of both man and machine. Tactical fighter aircraft, helicopters, VSTOL aircraft, agricultural-applications aircraft ("crop dusters"), and interplanetary and orbital vehicles are a far cry from the modest beginnings of the Wright brothers' biplane at Kill Devil Hill. Aviation pathologists, as well as other members of the aircraft-accident team, are faced with a herculean task to keep pace with the rapidly developing aerospace technology.

The techniques of aviation pathology have been progressively advanced and refined to coincide with modern concepts of interdisciplinary investigation. The object of this session was to present some of these advances that have been made in aviation pathology and to relate the application of these methods to the recent experiences of the participants in accident investigation.

The session begins with presentation of early efforts in aircraft-accident investigation and organization, development, and planning to cope with aircraft catastrophes. Subsequent presentations describe jurisdictional and other medicolegal problems that are encountered and special methods that the aviation pathologist may employ to aid in evaluation of the postmortem findings. These methods include developments in toxicologic examination of tissues, roentgenographic evaluation, analysis of specific injuries and injury patterns, and study of psychological factors. The discussions that followed the presentations provide additional insight into and expansion of the recent advances and experiences described by the authors.

The information presented at the session should serve as a valuable guidepost describing the state of the art in aviation pathology as of 1976.

Robert R.McMEEKIN, M.D.
LTC, US ARMY, Medical Corps
Session Chairman

CONTENTS

TECHNICAL-EVALUATION REPORT

The session began with reviews of organizational concepts of fatal aircraft-accident investigation as developed and applied in the United States, Germany, and France. Subsequent presentations provided an organized approach to the application of special techniques to solving current problems of great mutual concern.

Determination of medical jurisdiction is frequently chaotic. The long-range capabilities of modern aircraft frequently require the application of local, state, national, international, and admiralty law. Immediate determination of the appropriate applicable laws is the first obstacle that the accident investigator must face. Geographical and territorial boundaries even make accidents involving short-range aircraft the subject of this dilemma. During the discussions at this panel meeting it was suggested that an AGARD publication be undertaken to evaluate these jurisdictional problems critically.

Simple, logical applications of basic methods of identifying victims of mass disasters were reviewed. Careful application of these techniques should relegate this aspect of the investigation to the minor category to which it belongs, leaving more time available for determination of causative factors in aircraft accidents.

Discussions of cardiovascular disease, head injuries, and accidents involving helicopters and agricultural aircraft prompted expressions of frustration at the lack of significant modification of the epidemiology of these factors, in spite of major progress in the elucidation of the various causative factors. A broad spectrum of problem areas was cited, ranging from the failure of designers, engineers, manufacturers, and crew members to accept unequivocal evidence from research supporting modifications of designs and operational procedures to the continuing quandary of cost effectiveness. A notable exception was the experience of the U.S. Army with the installation of crashworthy fuel systems and the resultant essentially complete elimination of the problem of fatal burns in aircraft accidents.

were made

Presentations of significant advances in the application of special techniques in histology, toxicology, radiology, and analysis of injury patterns, initiated prolonged discussions among the participants. Recent progress in the expanded application of radiologic techniques to new areas of accident investigation and injury analysis was especially encouraging. A desire for further in-depth exchanges of ideas was clearly apparent and will provide added stimulus for future AGARD publications and panel sessions. The unanimous intent to discard obsolete methods and to initiate a bold, probing search for new techniques free from the preconceived self-limiting ideas of the past was expressed.

Although investigations of the causes of fatal accidents were conducted as early as World War I, the multidisciplinary aspects of medical contributions to these investigations were not fully appreciated until the 1950's. The rapid development of aviation pathology in the past 20 years has been primarily the result of international cooperation of the NATO member nations. The causes of many accidents would remain unexplained were it not for the discussion and exchange of information that have taken plase at AGARD meetings such as this session of the Aerospace Medical Specialists' meeting. The significance of the monumental endeavors of past and present contributions to these sessions can be measured only in terms of lives saved, injuries prevented, and accidents averted.

DEVELOPMENT OF AIRCRAFT ACCIDENT INVESTIGATION PROGRAM AT THE ARMED FORCES INSTITUTE OF PATHOLOGY

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The Armed Forces Institute of Pathology had its beginning in environmental medicine related to combat and noncombat functions of military services with the American Civil War. With the advent of an aviation arm of the military, it was only logical that the AFIP should expand its role to encompass environmental problems and accidents relating to aviation medicine. The Aerospace Division established in the 1950s pioneered both military and civilian aircraft accident investigation in the United States through a cooperative arrangement with the FAA, and helped to establish procedures for civilian accident analysis. The AFIP became a centralized evaluation center for toxicology and histopathological evaluation of all U.S. military aircraft accidents. To facilitate this mission and recognizing its importance, the Joint Committee on Aviation Pathology was established by the Department of Defense in 1955.

Although there had been some prior casual endeavors in medical investigation of fatal aircraft accidents, it was not until the early '50s that interest began to kindle in the United States. With the British investigation of the Comet disasters and the increasing volume of air traffic in the United States, the advantages and benefits of thorough investigation of aircraft accidents became readily apparent in both military and civilian aviation.

The military, with their increased flying efforts and increasing emphasis on flying safety made the first step. It was only natural for the military to turn to the Armed Forces Institute of Pathology for their pioneer efforts in the newly developing field of interest. The Armed Forces Institute of Pathology was founded in 1862, as the Army Medical Museum, and charged with the mission of consultation, research and education in the broad field of pathology. The initial stimulus was generated by inadequate medical knowledge to reduce the high morbidity and mortality of the military engaged in the American Civil War. Specimens were collected, analyzed in depth and conclusions drawn to develop educational seminars to better acquaint the battalion surgeon with the most effective methods to render medical assistance to the war casualties. Pursuing the original charge, in subsequent years the AFIP developed into the greatest centralized collection of expertise in pathology within the United States, and perhaps throughout the world.

With the new mission, the AFIP went to work. Dr. Vernie Stembridge was assigned the task of developing the new aviation pathology division. All the previous material on file was collected and reviewed. Development initially was slow, but persistent forward motion was apparent. As in any new effort, the first question to be answered was, "What are we looking for?" After much thought, this was digested to a very simple level of evaluation with three cardinal principles governing medical support of fatal accidents: environmental factors, traumatic factors, and pre-existing disease processes.

Having established the tenets, application of the tools of the forensic pathologist to the problem at hand was initiated. The importance of the function was recognized by the Department of Defense in 1955 with the formation of the Joint Committee on Aviation Pathology. This Committee brings together representation from the United States, Great Britain, and Canadian military forces with expertise in aerospace medicine and pathology for periodic discussion of operational problems and recommendation of solutions.

One of the fields, with obvious application, was toxicology. Analytic methods for important modifying factors, such as carbon monoxide, alcohol and other drugs were very crude and nonspecific at that time. Environmental factors such as carbon monoxide and fuels were given top priority along with development of a procedure for lactic acid to detect hypoxia. Screening procedures for alcohol and drugs were also developed. The original procedure for alcohol, which encompassed all reducing substances and all alcohols including those resulting from putrefaction, initially produced totally unsatisfactory results. Searching for more specific data, new tools such as the gas chromatograph, ultraviolet spectrophotometer, mass spectrophotometer, electrophoresis, and most recently, radioimmuno assay have been applied. Currently a screen is conducted on each specimen for carbon monoxide, ethyl alcohol, lactic acid and acid-basic-neutral drugs, which may have altered the flight performance of the individual. Development of procedures to meet the requirements of the aviation pathology division has resulted in the publication of approximately 35 papers in professional literature and 3 book chapters.

To support research aspects in addition to toxicology, in the late 1950s an altitude chamber, which was excess at another base, was installed at the AFIP. It is small as compared to aircrew chambers, but has proved adequate for such studies as the pulmonary effect of 100% oxygen at altitudes of 35,000 and 43,000 feet, using dogs as the experimental subjects, and evaluation of a blood gas analyzer's performance at altitude. Other studies have been performed in hyperbaric medicine as applied to bacterial growth.

With the physical size of the United States of 3 million square miles, or 8 million square kilometers, extending approximately 3,000 miles east and west and 1,500 miles in the greatest north-south dimension, it readily became apparent that one facility to travel to all accident sites was not practical. Efforts were then initiated to establish regional investigators, consisting of pathologists with support personnel from military hospitals throughout the U.S. and overseas, using similar protocols for autopsy, photography, x-ray and toxicology. The results are forwarded to the central facility at the AFIP for review and correlation of findings. A centralized laboratory for toxicology processes all specimens. The regional teams generally consist of a pathologist, medical photographer and either histotechnologist or administrative assistant. Equipment is carried, except for x-ray, to perform a complete examination and collect specimens for further anatomical and toxicological examinations. Administrative arrangements were established to transport the investigation team to the accident site by the most expeditious means possible. Only under unusual circumstances, such as complex equipment or large numbers of casualties, has it been necessary for personnel from the central facility to travel to the site. They remain readily available for consultation by telephone. During the period of a year the division will process approximately 400 - 600 cases, of which approximately 300 are military and the balance referred for consultation from the civilian sector. The cases represent individual fatalities and not total accidents. Six to ten on-site investigations are conducted by AFIP members annually, which may be either a military accident or in consultation with the National Board of Transportation. Since the division was established approximately 200 scientific papers have been published summarizing some of their efforts.

Initially the division performed many of the civilian accident investigations for the Federal Aviation Administration. However, as time passed, the FAA established its own branch, patterned after the AFIP model, to investigate commercial and private aviation accidents. The AFIP remains as a consultant to this group.

An annual course is sponsored by the AFIP to update pathologists and flight medicine specialists who are likely to be involved in aircraft accident investigations.

The division has been expanded in recent years as more material is accessioned and knowledge increases. Improvement efforts to better evaluate the material and upgrade the division are constantly under way.

DISCUSSION

McMEEKIN: Most physicians have little, if any, exposure to methods of aircraft-accident investigation, and it has been difficult to find flight surgeons and pathologists who are willing to make the professional sacrifice necessary to obtain expertise in aviation pathology. The number of physicians in this field is small compared to the number of fatal accidents. Where do you propose to obtain the necessary additional personnel?

COWAN: Efforts are under way to have all new pathologists entering the Air Force attend the AFIP short course in Aviation Pathology during their first year of service. Presentation of similar material to all candidates in the primary course in Aviation Medicine will continue.

FUCHS: All flying forces of NATO components are very much interested in receiving information on the work of the Joint Committee on Aviation Pathology and in participating in the JCAP activities. How shall we increase the exchange of information? Can JCAP invite other NATO-component forces?

COWAN: All NATO-force medical representatives have been invited to participate in the biennial scientific sessions of JCAP. Some have done so. To add additional members would require a new charter for the organization from the Department of Defense. A revision of the charter is not feasible at the present time.

UNTERHARNSCHEIDT: Please comment on the standardization of autopsy procedures and the evaluation of the findings.

COWAN: The suggested standardized procedure is described in the triservice autopsy manual (Autopsy Manual TM 8-300/NAVMED P-5065/AFM 160-19), which is currently under revision with specific attention to this topic. X-ray films, photographs, toxicologic analysis, and scene diagrams are addressed in the revision. Reporting is on Standard Form 1322, and all findings are evaluated at the AFIP.

UNTERHARNSCHEIDT: Is x-ray examination of the cervical spine and skull routinely required? If so, how many planes:

COWAN: Usually the requirement is stated as being for total body PA and lateral x-ray films without specifically listing individual areas such as the cervical spine. The condition of the bodies and available x-ray facilities frequently limit additional studies.

UNTERHARNSCHEIDT: Which areas and how many blocks are required for histopathologic examination of the brain and spinal cord?

COWAN: There are no specific requirements for neuropathologic examination. Again, the condition of the specimen influences the judgment of the pathologist's decision in selecting appropriate available histologic sections to document the damage.

DEVELOPMENT OF AVIATION ACCIDENT PATHOLOGY IN THE FEDERAL REPUBLIC OF GERMANY

by

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German Air Force Institute of Aviation Medicine
Fürstenfeldbruck

Through the accomplishments of technology, medicine is permanently confronted with new tasks and problems which must be tackled and solved in the interest of avoiding dangers which are threatening man when dealing with these achievements of technology and while penetrating into ever greater heights. This necessitates special fields of research and knowledge within medicine, such as for instance aviation medicine, aviation physiology, aviation accident medicine and, last not least, also aviation accident pathology. The last mentioned speciality shall be dealt with in detail as follows.

Being an applied branch of medical sciences, aviation accident pathology serves the research into the causes, effects and bodily alterations, caused by aviation-specific conditions and events within the human and animal organism (i.e. animal tests).

RESPONSIBILITIES AND PROBLEMS OF AVIATION ACCIDENT PATHOLOGY
result from man- air vehicle- environmental interfaces which come to bear on man not only during flight, but possibly also during accident events.
While flying and penetrating into ever greater heights man in the aircraft - and sometimes also without - (e.g. parachuting, catapult ejection) is exposed to flight-specific influences. These are the result of the effects of various acceleration forces stemming from respective airspeeds, changes in direction of flight and motion of the air vehicle, and also from alterations of the athmospheric environment in the altitudes (effect of altitudes). Further influences might be caused by the construction and function of the air vehicles with their diverse configuration and equipment (e.g. pressure cabin, oxygen equipment, survival equipment etc.). Degree of disturbance and damages in the human organism are dependent upon intensity, type, and duration of flight-specific influences. Even casualities may thus be caused.

As taught by experience, accidents are not based on coincidence, but always on concrete causes, which for the greatest percentage are inherent in man, that means in the flying personnel, followed by other factors such as technical deficiencies, wheather, bird-strike, foreign object damage, shortcomings on airbase installations a.so., according to new investigations. The percentage of human factors in aircraft accidents is as follows:

In the general civil aviation such as for purposes of sports, tourism and general business purposes (utility)	between 80 % and 90 %
In military aviation	between 65 % and 75 %
In airline traffic	between 50 % and 60 %

With increasing sophistication and further improvements of aircraft performance potentials in the years ahead, it must be reckoned that the technology factors as aviation accident cause will further decrease, conversely, the increasing demand on man will cause a further elevation of this factor, provided adequate counter-measures are not initiated. Because of the rapid growth of aviation in its various fields, incidents and accidents these days are experienced much more frequently than in earlier times, even though thanks to intensive efforts, it was possible to continuously decrease the accident figures - related to transport capacity - and consequently make the air vehicle into one of the safest means of transportation presently at our disposal.

THE IMPORTANCE OF AVIATION ACCIDENT PATHOLOGY FOR THE PREVENTION OF AIRCRAFT ACCIDENTS AND FLYING SAFETY
Incidents and accidents in aviation require thorough investigations for safety reasons, in order to clarify in minute detail causes and accident sequence. It is only through a clear knowledge of the accident causes that specific countermeasures may be initiated.

Caused by the high velocity and the force of impact of the aircraft resulting from it, which is frequently complicated by impact fire and explosion, aircraft accidents often have a high contingent of fatalities and severely injured, and quite often there are no survivors. Through his medical aircraft accident investigation the aviation pathologist due to his specific pathologico-anatomical examination of the fatally injured aircraft occupants is able to contribute essentially to the clarification of cause and sequence of such events, even more so because the aforementioned man-machine-environmental-interfaces have a highly intensive effects on the affected man in the accident event. At the site of the accident it is of utmost importance to determine these interfaces on the basis of traces and findings at the scene of the accident, on the aircraft wreckage, respectively its fragments, on the survival equipment, clothing and bodies of the fatalities. Frequently the bodies of the accident fatalities are mutilated through mechanical forces, fire or explosion and not infrequently they are severely disintegrated. Reconstructions of the bodies from the separate parts of the corpes become necessary not only to determine exactly the total number of fatalities, but also to identify them through application of special medical examination techniques. Type, specific site, extent and chronological order of external and internal injuries suffered and their mode of origin will have to be checked on the aircraft accident fatalities.

Frequently on the basis of injuries incurred it is possible to determine the whereabouts and special conditions of the respective individual in the aircraft, what functions he performed, in cases involving dual aircraft controls which of the two pilots had been in control of the aircraft and possibly which lever he had activated at the time of impact or collision. Cause of death, time of death, time of survival and sometimes also time spent at site of accident will have to be elicited in any case. In an endeavour to determine whether and to what extent the accident cause may be attributed to a failure of the pilot respectively other flying personnel the post mortem examination of the corpses will have to determine whether any acute or chronical diseases or health conditions due to accidents or surgical interventions have been involved, which under simultaneous flight-specific influences might have impaired the flying capabilities or even eliminated same altogether. Since flying capability may also have been impaired by selfmedication or by influence of toxic substances, as they occur in aviation, which in turn might have had a bearing on the accident, specimens of body fluids and tissues are removed during the autopsy to perform the necessary chemico-toxicological examinations. In a similar manner this applies to the histological examination of vital organs to prove diseases which an only come to light through microscopic examinations. Not seldom are aircraft accidents caused by criminal acts. In examining fatally injured aircraft occupants and the air vehicle, attention must therefore be devoted to traces, findings, and clues, which might point to such events, not to forget suicides. To clarify the highly diverse problems not only macroscopic, microscopic, and pathologico-anatomical examinations become necessary, but also supplementary examinations in the fields of trace analysis, X-ray, biochemistry and chemistry toxicology. Where infectious diseases are suspected, bacteriological examinations are also carried out. If investigations reveal bullet wounds, these examinations are augmented by ballistic and criminalistic investigations and background investigations. In cases involving fire the question will have to be checked whether the fire had started in-flight or only after impact and from which place in the aircraft it originated. The fatalities will have to be examined to determine whether the burns have been incurred during their lifetime or after they have succumbed, at the same time assessing the degree of burn injuries.

Since in the course of rescue-, removal-, and clearing operations many important traces and clues important for later reconstructions of the accident events are lost, it is of utmost importance that the aviation accident pathologist be included in the accident investigation procedure as early as possible. In this context attention must be called to the fact that corpses and parts of corpses undergo decomposition processes, which may make medical and chemical examination extremely cumbersome. Trace specimens necessary for supplementary trace analysis and for possible supplementary examinations must be secured at the time of the on-the-scene investigation while examining the wreckage respectively its debris. This applies likewise to the examination of the clothing of the affected and as a matter of course to autopsies. Further directives for the execution of the medical examination are to be found in the standardization recommendation number 3318 and in appropriate ICAO-directives. Aside from the fact that acute and chronic diseases and accident and surgical operation after-effects as well as intoxications impaired the performance capability of pilots, there may be several other conditions which exert accident-proneness, such as metabolic disturbances, nutritional deficiencies, effects of abnormal temperature influences, oxygen deficiency and abnormal influences of air pressure (Dysbarysm/Decompression sickness) as well as air sickness.

During the medical investigation of an aircraft accident the physician will have to collect and evaluate all traces, findings and facts, important for the reconstruction of accident events, in order to arrive at deductions concerning the accident sequence and the accident cause. Based on practical experience gained in accident investigations as well as on new knowledge derived from scientific work and research, suggestions and recommendations may be deduced, which serve to

1. Further technically improve air vehicles, especially their layout and equipment,
2. Improve the health protection of flying personnel and other aircraft occupants,
3. Improve rescue- and survival equipment,
4. Improve existing installations and regulations in flying operations,
5. Prevent or at least effectively diminish the number of aircraft accidents, and thus finally
6. Further improve flying safety.

Since aircraft accidents may have legal consequences, it may be augmented at this point that aviation accident and pathological examination findings are of special importance in civil litigations and may be of utmost importance with respect to protecting the interests of the injured victims and the surviving dependents.

The greater and more complicated an aviation vehicle created and to be operated by man, the more difficult and comprehensive medical and further supplementary examinations are necessary after an accident occurance. Because of the international character of air traffic, the cooperation of experts in the field of aviation accident pathology of the individual nations concerned becomes necessary.
In order to meet his responsibilities as aviation pathologist, the physician must have a good knowledge in the entire field of aviation medicine, pathology and last not least forensic medicine. He should be well familiar with the flying environment, with aircraft operational modes, their layout and equipment and also with their operating procedures, to be in a capacity to check whether and to what extent, to mention but one example, a rescue system in its design and function has fulfilled its purpose, whether it has been operated correctly and, as the need may be, for what reasons it has failed. In order to bring the often cryptogenic causes to light which might underly an aircraft accident, all means of modern medical investigations, diagnostics and examinations within the framework of aviation accident pathology must be put into operation. Often an autopsy alone will not suffice, moreover additional information relating to training, flying experience and training phase (status) must be obtained and probes must be conducted into the living conditions

and particulars of the flying personnel involved.

HISTORICAL DEVELOPMENT OF AVIATION ACCIDENT PATHOLOGY IN GERMANY

a) Before World War II

Ever since the invention of aviation,be it according to the "leighter than air" or "heavier than air" principle, there were incidents and fatal accidents in these fields. They gave impetus to delve into the causes in an effort to prevent incidents and accidents. At the beginning it were mostly technical causes which led to an incident or accident involving the sometimes extremely rudimentary constructed air vehicles. With interest aircraft designers and in addition the pilot devoted their attention to the ill-infated aircraft to obtain clues pointing to the accident cause through the investigation of the air vehicle. Technical investigations of this nature incorporated an inspection of the separate components of the airframe, tail assembly, wing and engine to determine, whether they had withstood flying stress from a functional aspect. Engines, controls, and even instruments were disassembled to ascertain whether they had caused any technical failure. With the advance of technology these investigations became more difficult and complicated and with the increasing size of the aircraft also more expensive. Thorough as the technical investigations of these accidents might have been, it was a fact that only approximately 10 to 15% of the accident causes could be uncovered. Because of the ever increasing technical improvement of the air vehicles, their layout and equipment, this percentage decreased steadily so that cases increased in which technical deficiencies could not be proven on the aircraft involved in accidents. From these findings it was then indirectly deduced that the cause of the accident would lie in an error or failure of the pilot. Even though it is true that in certain cases inexperience, carelessness, violations of flying rules or errors in manipulating the aircraft could be proven as accident cause, there still remained a relatively high percentage of unclarified accident causes. Among the fatalities there often were extremely reliably working and very experienced pilots, who could not be reproached with the allegations mentioned. In consequence there must have been other causes underlaying the accident sequence of events, which had to be determined in the interest of aircraft accident prevention and flying safety. No one had the idea to entrust physicians with investigative responsibilities necessary in aircraft accidents, in addition to pilots, designers, and technicians. During World War I and also for a long time thereafter physicians were asked to the scene of aircraft accident, but only for the purpose of determining the cause of death or in instances involving injuries to aircraft occupants for the purpose of giving medical aid, comfort and rehabilitation. At those times it was not customary to let physicians participate in aircraft accident investigations, an omission, which later on had to be paid for dearly and has led to numerous avoidable aircraft accidents with resultant increasing losses in man and material.

Numerous fatal aircraft accidents which occurredprior to World War II within the German Reich in connection with the activation of the former Luftwaffe gave rise to the institution of systematic pathological and anatomical examinations as well as aeromedical investigations. Since, as already pointed out, flying and technical investigations frequently did not suffice to bring about a clarification of the accident cause, one turned to the fatally injured man in the air vehicle hoping to gain further information on the accident sequence and accident cause through detailed pathologico-anatomical examination of the victim. It was for this reason that fatally injured pilots and moreover other flying personnel involved in fatal aircraft accidents were subjected to autopsies and other necessary supplementary examinations ever since 1934. In many cases it was only through post mortem examinations that the genuine accident cause could be established. A surprising finding in fatally injured members of the aircrew, who then still flew in an open cockpit, was the relatively high percentage of carbon monoxide haemoglobin in the blood of the corpses, which testified to the fact that the pilot must have crashed in a state of unconsciousness resulting from the inhalation of carbon monoxide gases. The same applied to the other members of the flying personnel. This fact was investigated. Later examinations of the respective types of aircraft revealed a faulty construction of the exhaust pipe of the radial-type engine still in use at that time, which was designed in such a manner as to cause exhaust fumes to pass over the heads of aircraft occupants in flight, thus forcing them to constantly breath this intoxicated air. Other causes bringing about CO intoxications in flying personnel were thus disclosed, such as cracks in the exhaust pipes, faulty design in heating devices a.s.o. Only after the technical elimination of these sources of intoxication and improvement of the acceptance rules was it possible to do away with such accident causes. During the pathologico-anatomical examination of the fatalities, injuries were checked with a view towards their infliction and a determination of the causing object, and many valuable traces were found for the reconstruction and assessment of the sequence of events. They gave rise to multiple improvements in aircraft design, predominantly in interior design and layout of the aircraft. Not only aircraft, but also self-rescue devices were examined, whether and to what extent they met the criteria for their special use and whether in emergency situations the aircraft occupants had utilized them in the prescribed manner, and, if applicable, why they had failed. The same applies also to oxygen supply and breathing masks, all the more since an increase in the performance potential of the aircraft enabled the pilot to fly at even greater altitudes. During the autopsies of the fatalities it was examined whether and to what extent the accident cause in flying personnel could be linked to acute or chronic diseases, accident or surgical intervention after-effects and possibly their interrelationship with flight-specific elements. By supplementary chemico-toxicological examination it was even then possible to clarify the causes of many incidents and accidents in flying operations which were not only prompted by the inhalation of CO-toxic exhaust gases or the fumes of fires, but also by inhalation of oil or fuel vapors respectively other flight-specific chemical substances.

At the Institute of Aviation Accident Pathology of the University in Freiburg under the direction of Prof. Dr. BÜCHNER and his collaborators scientific methods were used in the examination of pathological and anatomical changes in organs and structure caused by lack of oxygen. In other institutes of aviation medicine in Germany the influence of abnormal air pressure, gusts of wind, temperature and acceleration forces were looked into through experiments with animals and on man. Moreover explosive decompression, windblast and vibration and their effects on biological material were the subject of research. With a view towards their effects on animal and human organism specific injuries incurred through a wide arrey of weapons were also studied. Problems of survival in emergencies over water and elsewhere, as well as under heat and cold stress were other subjects of intensive research. The results of this research work were then published in the periodicals "Zeitschrift für Luftfahrtmedizin, Luftfahrtmedizinische Abhandlungen, Mitteilungen auf dem Gebiet der Luftfahrtmedizin" and in other specialized medical publications. During World War II technical research was accelerated and aircraft were not only constantly improved in their performance potentials, but also in their layout and equipment. New problems arouse which in the interest of recognition of danger and timely management of danger respectively avoidance had to be solved for operational reasons. For these reasons aviation accident medicine and aviation accident pathology was carried on throughout World War II in practical application as well as purposefully directed research. Because of the outcome of the war, the results of this work were only published after the war in two volumes under the title: "German Aviation Medicine in World War II" in America (Washington, 1950).

b) After World War II

The successful work of German pathologists and forensic medical experts in the field of military aviation was abruptly cut off upon the unconditional surrender of the German Armed Forces in the spring of 1945. The former facilities and installations of activity were lost, scientists who had survived the war devoted themselves to other fields or went abroad. As a result of the restrictions imposed on German Aviation all work in this field ceased for more than a decade. In full realization of the high value of aviation accident pathology to aircraft accident prevention and thus to flight safety this field was advanced abroad and the pertinent institutions were considerably expanded, particularly after pathologico-anatomical examinations of the victims of the Comet-disaster yielded surprising pathologico-anatomical findings. To facilitate an exchange of aviation pathological experience and new scientific knowledge on a wide and broad basis and enable aviation to take advantage of it, aviation accident pathologists in the USA, Canada and England in 1951 met in the Joint Committee on Aviation Pathology, which periodically every 2 years holds a special conference lasting for several days, at which papers are presented on research results.

In the Federal Republic of Germany the field of aviation accident pathology acquired significance again when the restrictions with regard to aviation were relaxed and lifted and when a new air force had to be established for the defence of the country upon adoption of the compulsory military service legislation in 1956. With the steady increase of flying operations in the civil but also military sector, the number of incidents and accidents began to rise from year to year. In the interest of aircraft accident prevention and flying safety these accidents required a thorough investigation to clarify the cause and sequence of events, including the persons involved. For this reason the division of aviation accident pathology at the German Air Force Institute of Aviation Medicine in Fürstenfeldbruck was activated on the 1st of April 1964 and steadily expanded. This division is not only responsible for aviation accident medicine but above all for aviation accident pathology and aviation accident toxicology in practical application, accademic training and purposeful research work. Housed in one brick building and five pre-fabs, there are 20 persons presently engaged in work, among them three physicians with forensic respectively pathologico-anatomical training and one chemist. In all cases involving major aircraft accidents of the military aviation of the Bundeswehr the division chief respectively his deputy are alerted and conduct the necessary medical and pathological examinations on the scene of the accident with a trained investigation team. The supplementary X-ray-, trace-, histological, biochemical and chemico-toxicological examinations as also recommended in standardization agreement number 3318, are performed in the laboratories of the division of aviation accident pathology. Autopsy protocols , statements and expert opinions are prepared as expeditiously as possible and forwarded to the Surgeon General German Air Force and General, Flying Safety for further action. In aircraft accident boards physicians participate in their capacity as experts and in doing so they not only interpret their findings but also discuss improvement proposals. In order to arrive at the scenes of accidents as speedily as possible, the division is equipped with a mobile accident vehicle which is driven to the site of the accident in cases involving short distances and via cargo aircraft to long distance scenes. In this manner any place of accident within the Federal Republic may be reached within 2 1/2 hours at the latest, a procedure which has paid off extremely well. For mass disasters the division has at its disposal an additional disaster vehicle adequately equipped for such a task. To clarify diverse problems arising from aircraft accident investigations, pinpointed research work is applied. Its results are presented in meetings and conferences on a national and international level and also laid down in publications, of which more than 50 papers have appeared since the division has been activated.

A broad spectrum of activity within the framework of responsibilities is occupied by training and advanced training of physicians, flying safety officers and paramedical personnel(flight surgeons' assistants).They are familiarized with the latest state of art in the fields of aviation accident medicine, aviation accident pathology, and aviation accident toxicology to enable them to perform in an optimal manner at the scene of the accident. All in all the work done by the division of aviation medicine has had extremely profitable effects on military aviation. Beyond this the collaborators of the division for aircraft accident medicine are invited to participate in aircraft accident investigations by the Federal Aviation Authority, as concerns airline and civil aviation in the Federal Republic. Thus, Armed Forces medical experience could be applied to the benefit of civil aviation.

SUMMARY
The author reports on the development of aviation accident pathology in Germany with special emphasis on the particular situation, as it existed prior to and after World War II. Particularly in the field of accident pathology pioneerwork has been done in Germany, which has proven of extreme benefit to aircraft accident prevention and therefore to flying safety. In line with the development in aviation even greater importance will be accorded this speciality in the future.

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DISCUSSION

McMEEKIN: You have the perspective of many years' experience in investigating fatal accidents. Do you believe that we are making progress? Are the engineers listening to our recommendations?

KREFFT: Yes, I think we are making progress. Some engineers do listen to our recommendations, but we should discuss the problems with the engineers before a new aircraft type is delivered.

WARD: If highly trained and experienced pathologists are not available to investigate fatal accidents, what group of physicians would you recommend?

KREFFT: Although extensive training and experience is desirable, flight surgeons receive basic instruction in accident-investigation techniques and are able to develop experience in time.

PLACE ET ROLE DES SERVICES MEDICAUX DANS LA SECURITE DES VOLS
ETUDE SUR L'ORGANISATION ET LES MOYENS
MIS EN OEUVRE DANS LES FORCES AERIENNES FRANCAISES

par

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F R A N C E

RESUME

Les différents niveaux et modes d'intervention du Service de santé dans le déroulement et l'exploitation des enquêtes après accident ou incident aériens sont analysés en fonction des dispositions réglementaires et des procédures en vigueur dans les Forces aériennes françaises. Certaines dispositions ainsi que la contexture du compte rendu d'enquête ont été récemment révisées. Les modifications déjà appliquées ou en cours de réalisation, doivent permettre d'élargir le champ d'investigation des Services médicaux et faciliter l'exploitation des données recueillies.

INTRODUCTION

L'importance du facteur humain dans les causes d'accidents ou incidents aériens soulignerait, s'il en était besoin, la necessité pour les médecins de participer activement à la sécurité des vols. Les statistiques établies dans l'Armée de l'Air française sont, à cet égard, éloquentes.

Elles constituent un élément de réflexion qui conduit à s'interroger sur la pleine efficacité du Service de Santé dans la prévention des accidents.

C'est ainsi qu'il nous est apparu nécessaire d'examiner sous un aspect critique les modalités de l'intervention des services médicaux aux différents niveaux de leur action en matière de sécurité des vols.

Les problèmes de sélection et d'aptitude des personnels se situant en amont du sujet qui nous préoccupe, notre objectif s'est donc limité :

- A étudier en fonction des structures et des dispositions réglementaires en vigueur jusqu'en 1975, le fonctionnement de la chaîne médicale en cas d'accident ou d'incident d'aéronef.

- A présenter les modifications apportées au système en fonction des imperfections constatées.

LES STRUCTURES.

Pour tout accident ou incident d'aéronef, le service médical est concerné à différents niveaux :

- Au niveau de la Commission d'enquête.

Chaque accident survenu à un aéronef de l'Armée de l'Air donne lieu à l'ouverture d'une enquête dite normale ou réduite selon la gravité.

Parmi ses membres la Commission d'enquête comporte toujours un officier médecin.

Il s'agit généralement du médecin chargé du personnel navigant de l'unité à laquelle appartient le personnel accidenté. Il est l'adjoint du Président de la Commission pour tout ce qui concerne le facteur humain de l'accident.

Son rôle consiste en particulier :

  - A rechercher parmi l'ensemble des facteurs ayant déterminé la situation d'accident, ceux qui impliquent l'homme dans le système homme-machine.
  - A proposer au Commandement local toutes mesures urgentes qu'il estime nécessaires pour éviter le renouvellement de situations similaires.
  - A établir les comptes rendus réglementaires qui sont exploités à un échelon supérieur.

- Au niveau de l'échelon central.

Trois organismes du Service de Santé sont concernés par le déroulement et les suites de l'enquête :

  - Le bureau "accidents" du Centre de Recherches de Médecine Aéronautique (C.R.M.A.).
  - Le bureau de la statistique médicale du Centre Principal d'Expertise Médicale du Personnel Navigant (C.P.E.M.P.N.).
  - L'Inspection du Service de Santé pour l'Armée de l'Air (I.S.S.A.A.).

Parmi ces trois organismes directement concernés, mais indépendants les uns des autres, c'est le C.R.M.A. qui, du fait des dispositions réglementaires, des procédures d'enquêtes et des moyens qu'il possè-

de est, en principe, le plus immédiatement impliqué.

DISPOSITIONS REGLEMENTAIRES ET PROCEDURES.

Les dispositions réglementaires.

La Commission d'enquête normale doit permettre, à elle seule, de dégager toutes les circonstances et les causes de l'accident. Une fois cette enquête terminée il n'est pas nécessaire, en principe, de revenir sur l'accident.

Pour lui donner ce caractère définitif, la Commission d'enquête doit s'adjoindre, dès l'origine, et au fur et à mesure que la nécessité s'en fait sentir, tous les spécialistes les plus aptes à analyser les causes particulières incriminées. C'est ainsi que si le médecin membre de la Commission d'enquête l'estime nécessaire, un médecin du Centre de Recherches de Médecine Aéronautique peut être désigné pour renforcer la Commission. Cette désignation se fait sur la demande de l'Etat Major de l'Armée de l'Air qui doit être saisi par le Président de la Commission. Notons donc, au passage, que l'intervention du Commandement est nécessaire. Toutefois, les spécialistes désignés par leurs autorités respectives, pour constituer la Commission d'enquête dite "renforcée", ne sont pas subordonnés au Président de la Commission. Ils travaillent en liaison avec lui ; ils lui communiquent les résultats de leurs recherches mais n'ont, dans la Commission, qu'un rôle consultatif.

Le Centre de Recherches de Médecine Aéronautique peut être sollicité dans un autre type d'enquête appelée "enquête spéciale". Les enquêtes spéciales ont pour but d'étudier l'aspect général de certaines causes techniques, opérationnelles, médicales ou météorologiques d'un ou plusieurs accidents particuliers. Lorsqu'il s'agit d'un problème médical, l'enquête spéciale est menée par le Directeur du C.R.M.A. soit directement sur sa proposition, soit sur ordre du Ministre de la Défense, soit sur la demande du Chef d'Etat Major de l'Armée de l'Air.

Ces dispositions impliquent par conséquent que les éléments médicaux de l'échelon central soient alertés en temps voulu et correctement informés ; c'est-à-dire que les procédures soient adaptées et correctement appliquées.

Les procédures.

Pour chaque accident aérien le Médecin enquêteur rédige le dossier médical du rapport d'enquête et il le remet au Président pour être joint aux différents exemplaires du rapport.

En outre, un certain nombre d'exemplaires de ce dossier médical sont adressés directement par le médecin aux destinataires "Santé", à savoir :

- Le Centre de Recherches de Médecine Aéronautique.
- Le Centre Principal d'Expertise Médicale du Personnel Navigant.
- Le Directeur du Service de Santé de la Région Aérienne concernée.
- Le Médecin Général Inspecteur du Service de Santé pour l'Armée de l'Air.

Le Président de la Commission doit expédier les exemplaires du rapport dans un délai maximum fixé à douze jours à compter de la date de l'accident. Le Médecin est donc tenu d'observer ces mêmes délais. C'est-à-dire que, compte tenu du temps d'acheminement, les destinataires "Santé" ne reçoivent les dossiers qu'ils sont chargés d'exploiter qu'une quinzaine de jours après l'accident.

Ce long délai, dans un certain nombre de cas, peut être gênant. Il est vrai que l'inconvénient n'existe pas pour le Commandement, car dans les 24 heures qui suivent son arrivée sur les lieux de l'accident, le Président de la Commission d'enquête est tenu d'envoyer un "message d'enquête sommaire".

Ce message a pour but :

- De confirmer et de préciser les renseignements déjà envoyés dans les messages initiaux d'avis et de confirmation d'accident.
- De faire le point des résultats obtenus par la Commission d'enquête.
- De demander éventuellement les spécialistes nécessaires au renforcement de la Commission.
- De demander éventuellement une enquête spéciale.

C'est donc à ce niveau et à ce moment que le Médecin enquêteur peut, s'il l'estime indispensable, faire mentionner dans le message d'enquête sommaire qu'une enquête renforcée est demandée, c'est-à-dire qu'un Médecin spécialiste du C.R.M.A. doit être désigné pour participer au travail d'enquête.

Ainsi, l'échelon central "Santé" et en particulier le bureau accident du C.R.M.A. , ne peut en fonction de ces procédures, participer au travail de recherches que pose éventuellement l'intervention du facteur humain dans un accident que si le Médecin d'unité navigante, chargé du travail d'enquête, juge, en moins de 24 heures, de la nécessité de renforcer la Commission par la venue d'un Médecin expert.

Sans mettre en cause la compétence des Médecins enquêteurs, il faut bien admettre que la tâche est complexe et que la décision de faire appel à un spécialiste peut ne pas s'imposer immédiatement. En tous cas, l'utilisation de cette possibilité s'avère, en pratique, extrêmement rare.

En résumé, dans les cas les plus fréquents le bureau accident du C.R.M.A. ainsi que les autres échelons hiérarchiques du Service de Santé pour l'Armée de l'Air ne sont informés de la nature, des circonstances et des causes d'un accident aérien, qu'à l'arrivée du dossier médical d'enquête transmis directement par le Médecin enquêteur. Au long délai déjà signalé pour que ce dossier leur parvienne, s'ajoute l'inconvénient de ne pas avoir connaissance du dossier complet de l'enquête puisqu'ils n'en sont pas desti-

nataires. Le traitement des données de l'enquête se fait donc en temps différé sur un dossier dont la contexture est schématiquement la suivante :

- RAPPORT DE L'OFFICIER MEDECIN ENQUETEUR.

Le dossier comprend des fiches collectives, des fiches individuelles et des fiches intercalaires.

- La fiche collective contient les renseignements généraux sur l'accident ou incident. (Nature de l'évènement - bilan général - circonstances et déroulement - avis de la Commission sur les causes - inventaire des fiches intercalaires jointes - observations diverses, en particulier, sur les secours d'urgence - un résumé des suggestions et des propositions de la Commission ainsi que des photographies).

- Les fiches individuelles sont de 2 types. Elles concernent :

  . Les membres de l'équipage accidenté.

  . Les passagers tués ou blessés ou toute personne tuée ou blessée en dehors de l'aéronef.

- Les fiches intercalaires sont destinées à préciser les causes des accidents et incidents. Il est rédigé autant de fiches qu'il est noté de causes ou cas particuliers (anoxémie, accélérations, etc...).

A la lumière d'une expérience portant sur plus de dix années, il est apparu que ce dossier médical d'enquête, tel qu'il est constitué, est à l'origine d'un certain nombre de difficultés dans son exploitation. Deux ordres de critiques peuvent être énoncés :

- Des critiques sur la forme.

  . Les renseignements généraux (nature de l'évènement, circonstances de l'accident, etc...) sont notés par le médecin. Les données qu'il recueille et transcrit apparaissent souvent insuffisantes, incomplètes ou tronquées.

  . En ce qui concerne les fiches intercalaires et dans le cas, par exemple, d'accident de cause indéterminée ou diverse, le médecin à qui est imposé un cadre strict a parfois tendance à se cantonner dans la recherche des seules causes classiquement inventoriées, objet des fiches, et à se désintéresser de la poursuite de l'enquête lorsque ces causes ne semblent pas en jeu. Il arrive au contraire que, dans l'incertitude, plusieurs fiches soient annexées au dossier, ce qui conduit à des répétitions, des inutilités et peu de clarté.

- Des critiques sur le fond.

Il est apparu que le fait de faire figurer au dossier complet d'enquête toute une série de données et de renseignements d'ordre strictement médical conduit souvent le médecin à limiter son action dans l'approfondissement de l'enquête. C'est ainsi, par exemple, que dans le souci légitime d'éviter la recherche et la divulgation de renseignements susceptibles de porter atteinte au "moral" du Personnel Navigant ou des familles, le Commandement ne souhaite généralement pas que des examens post mortem, dont le compte rendu figurerait au dossier, soient réalisés. Cette attitude résulte, en fait, d'un phénomène plus profond de répugnance vis-à-vis de la pratique des autopsies.

Ainsi, au vu de cette analyse, et les structures étant ce qu'elles sont, on s'est rendu compte que tant au niveau des dispositions réglementaires et procédures, qu'au niveau de la contexture du rapport d'enquête lui-même, il existait des causes alourdissant et compliquant le système ainsi que des carences limitant le bénéfice que l'on peut tirer des données des enquêtes.

C'est pourquoi, en accord avec l'Etat Major de l'Armée de l'Air, un ensemble de nouvelles dispositions ont été prises et sont d'ores et déjà appliquées. Un certain nombre d'autres sont en cours de réalisation. Enfin, en fonction des possibilités, des améliorations peuvent être envisagées au niveau des structures elles-mêmes, ainsi qu'au niveau des moyens.

NOUVELLES DISPOSITIONS ET PROCEDURES.

Ainsi que cela a été souligné, si l'officier Médecin enquêteur fait partie intégrante de la Commission d'enquête et à ce titre travaille en liaison étroite avec les représentants du Commandement, il n'en est pas de même pour les organismes "Santé" de l'échelon central qui sont séparés des autorités de l'aéronautique militaire chargées des problèmes de sécurité des vols (3° bureau de l'E.M.A.A. et Conseil Permanent de la Sécurité Aérienne).

Afin de réaliser une meilleure intégration à ce niveau, il a été décidé que le Chef du bureau accident du C.R.M.A. serait le correspondant du 3° bureau de l'E.M.A.A. et du Conseil Permanent de la Sécurité Aérienne).

A ce titre des attributions nouvelles lui ont été accordées. Elles ne seront pas détaillées ici mais les points importants en sont les suivants :

- En matière d'information.

  . Le Chef du bureau accident est destinataire des messages d'avis d'accident et du message d'enquête sommaire. Ainsi, dès le déclenchement de l'enquête, il est informé de la nature et des circonstances de l'accident. De même il reçoit le rapport complet d'enquête établi sous la responsabilité du Président, ainsi que tous les avis émis aux différents niveaux de la hiérarchie.

- En matière d'action.

. Le Chef du bureau accident est habilité à prendre tous les contacts qu'il juge utiles et il peut provoquer tous les ordres nécessaires afin que les enquêtes médicales bénéficient sans délai de tout le support technique indispensable.

NOUVEAU DOSSIER MEDICAL.

Une des causes reconnues de la limitation des investigations médicales pratiquées à l'occasion des accidents ou incidents étant les réticences du Commandement à voir figurer dans un rapport des éléments susceptibles de porter atteinte au "moral", il a été admis qu'un double dossier médical serait désormais établi :

. Un rapport médical réduit qui est inclus dans le dossier normal.
Il conserve une contexture suffisante pour éclairer le Commandement sur la part du facteur humain dans les causes de l'accident ainsi que sur ses conséquences et les mesures éventuelles à prendre ; mais tout élément descriptif, en particulier d'ordre anatomopathologique, ainsi que le détail des recherches effectuées, en sont exclus.

. Un rapport médical approfondi à usage strictement santé qui, avant sa diffusion, n'est soumis qu'au Président de la Commission d'enquête pour observations et signature.

Il est évident que si l'exploitation des dossiers "Santé" fait ressortir un élément susceptible d'intéresser la Sécurité des vols, les autorités concernées en sont immédiatement averties. En outre, à partir de ces dossiers une synthèse médicale annuelle doit être établie. Elle constitue un complément à l'analyse effectuée par le 3° bureau de l'E.M.A.A.

MESURES EN COURS DE REALISATION.

A l'occasion des nouvelles dispositions qui vont dans le sens d'une plus grande liberté d'action du service médical, tout en assurant le maintien d'une étroite collaboration avec le Commandement, un travail de refonte du dossier médical a été entrepris.

Cette refonte vise un double objectif :

. Améliorer le contenu en informations du dossier.

. Améliorer la présentation pour une meilleure exploitation.

Le dossier "Santé" doit être conçu en fonction du mode d'exploitation envisagé et du but poursuivi. Le but, en dehors de l'exploitation immédiate, au coup par coup, est entre autre, au niveau du bureau accident, d'essayer de dégager, à partir de données enregistrées, une typologie des accidents. Cette finalité conduit à concevoir une contexture très structurée pour le rapport permettant un recueil aussi exhaustif et précis que possible des données. Nous ne faisons d'ailleurs que nous inspirer en cela de ce qui a déjà été réalisé dans certaines forces aériennes étrangères, aux ETATS-UNIS notamment.

La partie la plus importante du rapport qui ait été remaniée concerne les fiches intercalaires relatives aux facteurs spécifiques des accidents.

La fiche "malaise en vol" a été établie à partir d'une centaine d'observations faites en milieu hospitalier sur des sujets admis après incident aérien. Elle se présente sous la forme d'un inventaire analytique des symptômes classés par appareils. Elle constitue l'élément de base du dossier et doit normalement orienter le choix des autres fiches intercalaires.

Parmi celles-ci deux ont retenu particulièrement l'attention :

. La fiche "facteurs psychologiques" constituée par une liste fermée et où pour chacun des éléments retenus il est demandé de préciser s'il s'agit d'un élément déterminant, suspecté, ou seulement présent, sans rôle apparent dans l'accident.

. La fiche anatomopathologie et radiologie. Elle concerne un secteur d'investigation qu'il paraît particulièrement important de développer.

ROLE DU PATHOLOGISTE APRES UN ACCIDENT AERIEN.

D'une façon générale, le rôle du pathologiste en Médecine Aéronautique est mal défini aux yeux des non spécialistes. Il n'intervient pas seulement pour l'identification des victimes : sa connaissance des équipements et son expérience médico-aéronautique, sa spécialisation propre, doivent lui faire rechercher tout autant, sinon davantage, la cause de l'accident, plutôt que celle de la mort. Cette notion justifie donc sa participation plus fréquente aux enquêtes.

La recherche des facteurs humains à l'origine des accidents a été souvent réduite dans le passé au profit de l'intérêt porté aux causes techniques. Or, l'expérience de certains pays a bien montré la nécessité d'un examen complet du pilote, de l'équipage, des passagers, des équipements.

En effet, le pilote aux commandes au moment de l'accident, peut être identifié par le pathologiste ; la position des membres de l'équipage, les moyens de protection mis en oeuvre, permettent de juger de la soudaineté de l'accident ou d'une préparation au choc. L'étude des lésions des passagers, selon leur place, figurant sur les manifestes de bord, permet de reconstituer les forces d'impact, de déceler les zônes de faiblesse des moyens de protection, de préconiser l'amélioration des équipements de sécurité.

En outre, un aspect médico-légal peut être soulevé par la présence de plusieurs membres d'une famille parmi les victimes. La survie, même temporaire, de l'un d'eux doit être recherchée.

Enfin, la multiplication des actes de piraterie ou de sabotage doit faire suspecter une explosion à bord et pratiquer, par exemple, un examen radiographique des corps à la recherche de particules métalliques incrustées dans les parties molles.

Toutes ces raisons ont conduit les différentes commissions Atlantique ou Européenne à standardiser les examens et à préconiser l'adoption des recommandations formulées à l'annexe 13 de la Convention de l'Áviation Civile Internationale.

Selon ces recommandations, l'état qui conduit l'enquête doit favoriser l'autopsie par un anatomopathologiste expérimenté et assurer une coordination entre l'autorité judiciaire et l'enquêteur désigné.

ROLE DU PATHOLOGISTE DANS LES FORCES AERIENNES FRANCAISES.

Ainsi que nous l'avons dit la participation de l'anatomopathologiste aux travaux de la Commission d'enquête n'est pas systématique. Mais la pratique des autopsies et des investigations complémentaires, à partir des prélèvements, devrait être rendue obligatoire dans au moins 3 cas :

. Cas d'accident aérien de cause indéterminée, où l'étude des lésions anatomiques peut mettre en évidence, comme l'expérience l'a montré, une thrombose coronaire, une rupture d'anévrysme cérébral, etc...

. Cas d'accident aérien dû à une cause médicale suspectée et où l'hypothèse d'une anoxie de l'aéroembolisme, d'une blessure, d'un malaise, demande à être vérifiée.

. Cas où le Médecin enquêteur ou le Président de la Commission d'enquête ou le bureau accident du C.R.M.A. estime que l'autopsie peut fournir des éléments susceptibles d'éclairer l'enquête.

Dans ces éventualités le pathologiste doit être appelé systématiquement à renforcer la Commission d'enquête. Ce qui n'a pas été le cas jusqu'à présent. Néanmoins, dans le cadre des nouvelles dispositions réglementaires on peut espérer que ces recommandations seront appliquées et qu'au minimum, pour chaque accident, soit réalisée :

. Une étude approfondie des lésions avec prises de clichés radiographiques systématiques du crâne, de la colonne vertébrale, des ceintures, ainsi que des membres, en présence de signes cliniques.

Des fiches modèles, tout en servant de guide aux Médecins enquêteurs, permettront de systématiser ces examens.

- UNE FICHE D'EXAMEN EXTERNE.

A renseigner dans tous les cas, complétée par des photographies prises sur les lieux de l'accident et par des diagrammes lésionnels.

Elle doit préciser :

- Les renseignements généraux relatifs à l'accident.

. La position de l'accidenté, l'état des dispositifs d'évacuation et des équipements de sécurité, de survie.

- L'identification du sujet.

Celle-ci relativement aisée pour les missions en monoplace, fait nécessiter la recherche :

. D'indices extérieurs se rapportant aux vêtements, au contenu de poches, aux bijoux, etc...

. D'indices particuliers du corps : cicatrices, empreintes, cheveux, tatouages, denture...

- L'examen externe du corps.

. L'état du corps, des modifications après exposition au feu, à la boue, au carburant...

. Les causes apparentes de la mort (traumatisme, hémorragie, noyade...)

. L'inventaire des lésions des parties molles. L'emplacement et le degré exacts des blessures, brûlures, contusions et lacérations.

- UNE FICHE D'EXAMEN INTERNE.

A établir après autopsie complète. Au cours de cette autopsie des prélèvements sont conservés pour les études microscopiques, biochimiques, enzymatiques, toxicologiques. Ce dernier point de l'enquête apparaît d'un grand intérêt. A la recherche de l'oxyde de carbone, réglementaire depuis plusieurs années, doit s'ajouter prochainement celle de l'alcool, de la nicotine, puis, dès que possible, celle des drogues tranquillisantes et sédatives.

PARTICIPATION DU LABORATOIRE CENTRAL DE BIOLOGIE AERONAUTIQUE.

Le L.C.B.A. dispose de services de biochimie et d'histopathologie dont le rôle, au cours des enquêtes renforcées (ou spéciales), peut s'avérer prééminent. Le personnel compétent en biochimie et en anatomie pathologique, l'équipement en chaîne d'analyse, en microscopie photonique et électronique les destinent tout particulièrement aux études toxicologiques et lésionnelles.

A titre d'exemple, des dosages, à la recherche de l'oxyde de carbone dans le sang, sont effectués sys-

tématiquement dans tous les cas où le facteur humain est soupçonné. Le sang est en général obtenu à partir de prélèvements d'organes : parenchymes hépatiques ou pulmonaires. Dans un passé récent, ces prélèvements ont permis, à titre exploratoire, une étude histopathologique associée à une expérimentation animale, dont les résultats ont confirmé la nécessité de réaliser des prélèvements précoces pour qu'une hypoxie puisse être révélée. La même rapidité de mise en oeuvre est également requise pour les études enzymatiques.

Dans le domaine des critères d'identification, une étude a été également conduite en collaboration avec les services de stomatologie du C.P.E.M.P.N. Les conclusions se situent dans une perspective d'avenir : à partir d'un examen pantomographique des maxillaires, des indices ont été définis et codifiés. Cet examen, réalisable dans un centre d'expertise à l'admission, pourrait faciliter la surveillance de l'hygiène bucco dentaire mais aussi permettre l'identification des personnels en cas de nécessité.

CONCLUSION

L'évocation du rôle, encore trop modeste, du toxicologue et du pathologiste dans les examens pratiques à l'occasion des accidents aériens, terminera cet exposé. Leur intervention systématique paraît, en effet, déterminante dans les progrès que l'on peut attendre dans l'action des services médicaux en matière de sécurité des vols. Si quelques modifications de procédures et de règlementation sont apparues nécessaires, elles demeureraient sans grand effet si chacun n'était convaincu que tout ce qui peut être fait dans le domaine médical doit être réalisé afin que soit encore réduite la part du facteur humain dans les accidents.

DISCUSSION

WARD: Is the chief or chairman of the accident board from the same unit as the victim?

PINGANNAUD: No. Only the flight surgeon is from the same unit as the victim. [translation from French].

WARD: This separation in the composition of the accident board minimizes the influence of the victim's commander in allowing the investigators to find and report all relevant factors, including some that may reflect adversely on supervisory procedures.

McARTHUR: We have found that appointment of the medical officer from the unit from which the victim comes can create a conflict-of-interest situation. Does a similar problem exist in your experience?

PINGANNAUD: Yes, this can result in a lack of objectivity on the part of the doctor in charge. The doctor of the unit is the only one who knows the personal and family life of the pilots for whom he provides medical care. However, I think that this is an important advantage in the search for the cause of the accident. [translation from French]

AIRCRAFT-ACCIDENT AUTOPSIES: THE MEDICOLEGAL BACKGROUND*

by

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SUMMARY

The aviation pathologist seeking to perform autopsies on the victims of aircraft accidents may be faced with difficulties in obtaining authorization for autopsy examinations; these difficulties can vary from country to country and even within the same country, and may occur despite their being signatories to the Convention of the International Civil Aviation Organization.

In the USA, the National Transportation Safety Board has an overriding authority in the case of civil aircraft accidents. Following a military aircraft accident outside a military base, authority rests with the local jurisdiction. If the accident occurred on a base where the military enjoy appropriate jurisdiction, then the base commander may authorize autopsies on military personnel and, in the case of U. S. Army and U. S. Air Force bases, on civilian personnel also.

In the UK, authority rests with the coroner or the Scottish Procurator Fiscal. Cooperation between the Royal Air Force pathologists and the civilian authorities has been good.

It is suggested that in the USA it would be appropriate for the military to be granted power to authorize autopsies on the remains of victims of any military aircraft accident.

INTRODUCTION

Following any aircraft accident, the medicolegal authority in that area where it occurred is likely to exert its jurisdiction over the remains of any fatalities, with the right to authorize and carry out autopsies as it sees fit. This may result in frustration for the aviation pathologist, since the scope of any pathologic investigation initiated locally can be extremely variable. This paper will consider the various civilian medicolegal systems of inquiry found in the United States and the United Kingdom and the agreements of the member states of the International Civil Aviation Organization insofar as they affect the aviation pathologist or flight surgeon.

The medicolegal systems of the USA and the UK are representative of those found in many other countries. The medical examiner system of the United States is also found in Canada. England exported her coroner system far and wide, including to the USA. The Scottish "continental" system is comparable with systems found in many countries of Europe, Latin America and elsewhere, including parts of the American South originally colonized by the French. An understanding of the British and United States systems therefore provides an insight into many others.

The interests of the local medicolegal authority, of the aircraft accident pathologist and of any national authority may be somewhat different. The aircraft accident pathologist has several reasons for conducting his autopsies. He has an interest in helping to elucidate the cause of the crash, the sequence of events that led to the injury and death of each occupant and in helping to safeguard the interests of the deceased and their relatives.

A United States coroner, however, may be empowered to investigate only those deaths in which there is a suspicion of criminal activity (14); an aircraft accident is not likely, at least initially, to come within this group. Following a mass disaster, the government interest is primarily in elucidating the cause of the accident with a view to future aviation safety. If the probable cause seems obvious, a large number of autopsies could be regarded as unnecessary.

An ideal medicolegal system of investigation would require a full forensic autopsy, including any indicated toxicologic analysis, in any case in which death was not clearly due to known natural disease. It is possible, nevertheless, that the desirability of autopsy following an apparent accident may not be readily accepted by the coroner or even by a forensic pathologist who is probably sufficiently busy in any case with his own more routine work.

In assessing the extent to which a medicolegal system serves its purpose, one should therefore first consider the types of cases to be reported and thereby brought under medicolegal jurisdiction. Must someone have clearly died of "unlawful" means before his death is reported? A system in which criminality must be evident before any investigation is possible tends to defeat its own purpose, but this is often the case. Nor is such a system likely to uncover any environmental or occupational hazards or elicit the cause of an aircraft accident.

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*The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of Defense or of the Royal Air Force.

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Who may then authorize an autopsy in a notified case? This may be a legal figure not directly concerned with the investigation, and since autopsy is unlikely to be obligatory in every notified case, permission for autopsy may be refused. Following a major disaster, circumstances are more likely to produce compliance with the wishes of the Government investigator.

The aviation pathologist may be an observer, or he may be allowed to perform the autopsies. But how adequate are the autopsy premises? Can there be any offer of assistance in radiology, photography, toxicology, or forensic science? Who will pay for the extra work? If not the aviation pathologist, who will perform these autopsies - a general practitioner? A hospital pathologist? Or a forensic pathologist? Is there any pressure to release the bodies and to dispose of the whole mess as quickly as possible?

Until the introduction of the United States medical examiner system, there were in Europe - and in those countries with legal systems derived from Europe - basically two systems of medicolegal inquiry (1, 4, 12). One is represented by the English coroner system, and the other is the "continental system." There are several important differences in principle.

In general, where the coroner system is in use, the coroner is the single medicolegal figure within the jurisdiction and is independent of the police. He has the power of disposal of the bodies and of autopsy in a wide variety of cases in which death is considered to require investigation. He is empowered to hold an inquest. He may hold a coroner's court with or without a jury and with hearings in public. He may have power of commitment for trial. His powers are comprehensive and his activities are public.

Under the "continental," or civil law system, only deaths in which there is a suspicion of crime need be reported to the police or public prosecutor. A private police inquiry takes place. Autopsy permission may be obtained from the public prosecutor or the police but usually must be obtained from a judge. It may be difficult to obtain in other than apparently criminal cases. If permission for autopsy is refused, one can appeal to a higher court but with inevitable delay. In those countries that follow this system, however, facilities for forensic examination are usually excellent. Frequently, two pathologists must be present at such autopsies.

INTERNATIONAL CIVIL AVIATION ORGANIZATION

As a result of a convention held in Chicago in 1944, the International Civil Aviation Organization (ICAO), with headquarters in Montreal, came into being in April 1947, with the responsibility for coordinating all aspects of international civil aviation. Over 100 states (countries) are signatories. Notable exceptions are the USSR and the People's Republic of China.

Article 26 of the Convention on International Civil Aviation (Chicago Convention) deals with "Aircraft Accident Inquiry" and, as summarized in the "Forward" to Annex 13, "imposes an obligation on the State in which an aircraft accident occurs to institute an inquiry in certain circumstances and, as far as its laws permit, to conduct its inquiry in accordance with ICAO procedure." These procedures are described in the ICAO Manual of Aircraft Accident Investigation. Unlike the Convention itself, the Manual provides only guidance and carries no legal standing.

Annex 13 to the Convention (Aircraft Accident Inquiry) makes the following provisions:

"5.1 The State in which the aircraft accident occurs shall institute an inquiry into the circumstances of the accident. Such State shall also be responsible for the conduct of the inquiry, but it may delegate the whole or any part of the conducting of such inquiry to the State of Registry....

"5.4.4. The State conducting the inquiry into a fatal accident should, subject to the particular circumstances, encourage internal autopsy examination by a pathologist, preferably experienced in aircraft accident investigation, of those killed. These examinations should be expeditious and complete.

"5.4.5. The State conducting the inquiry should recognize the interdependence of investigation itself and the identification of the victims and should ensure coordination between the judicial authority and the investigator-in-charge.

"5.5. The State of Registry shall be entitled to appoint an accredited representative to be present at the inquiry.

"5.12 A State entitled to appoint an accredited representative shall also be entitled to appoint advisers to assist him at the inquiry.

"5.13. RECOMMENDATION. - Advisers assisting an accredited representative should be permitted, under his supervision, to participate in the inquiry....

"5.14. RECOMMENDATION. - Participation in the inquiry should confer entitlement to:

i) visit the scene of the accident;
ii) examine the wreckage...."

The pathologist traveling overseas as an adviser to his country's accredited representative thus enjoys a clearly defined status acknowledged by the government of the country in which the accident occurred. Although there can be no presumption that local officials will have any prior awareness of these agreements, an explanation of these agreements and of the need for pathologic investigation seems usually to result in a harmonious working relationship. When the host country is not a signatory to the Convention, ad hoc arrangements between governments are necessary, with resulting delay.

UNITED STATES OF AMERICA

United States' Coroner Systems

The developing American colonies adopted the English coroner system when the coroner was low in status and the system ineffective as a means of uncovering crime or revealing danger to the public welfare (5, 12). In much of the USA, the office of coroner remains a minor one and continues now, as in England then, to be political and elective, requiring no medical or legal qualifications.

Under these circumstances, with inadequate facilities and finance, the incumbent may have no conception of his possible role in safeguarding the health of the community. His concern may be the rapid and discreet disposal of cases brought to his notice. Medicolegal autopsies may be vanishingly rare.

The coroner's power to order autopsies may in any case not be unrestricted (12, 14). Most commonly, in the absence of violence, or unless death were demonstrably unlawful, the coroner may have no power to authorize an autopsy and may risk a suit against him if he should do so. Aircraft fatalities may come under the latter category.

When the coroner has authority for autopsy, he may choose to release the bodies of deceased military personnel to the military for autopsy, prior to signing the death certificate himself. When he does not have authority for autopsy, it is unlikely, in the absence of special provisions, that he can legally do other than release the bodies to the relatives. The remains of civilian personnel may properly be surrendered for autopsy to the authority of the National Transportation Safety Board (NTSB). (See section on the NTSB).

Fortunately, there are many jurisdictions with updated and efficient coroner systems (12). The coroner may still be elected or may be appointed by a commission. Legal or medical qualifications may be required. In any case, if he is suitably motivated and provided with an adequately financed department and forensic pathology staff, he is capable of providing the cooperation and assistance sought by the flight surgeon or aviation pathologist.

United States' Medical Examiner Systems

The deficiencies of the traditional coroner system has led to its replacement in many jurisdictions by the medical examiner (ME) system.

Massachusetts was the first State to introduce the system, in 1877. New York followed in 1918 and was the first jurisdiction to require that the Chief Medical Examiner (CME) be a qualified pathologist. A model Post-Mortem Examinations Act was adopted by the National Conference of the Commission on Uniform State Laws in August 1954 (10).

In certain States, the office of Coroner is a constitutional one and cannot be abolished by statute (2). To effect a change-over, the office of Coroner may continue to exist bereft of power or may be incorporated into the medical examiner system.

The medical examiner system combines features of the coroner and continental systems. The medical examiner is the single medicolegal authority within the jurisdiction. He has stated minimal qualifications and is appointed usually by a commission. A wide range of cases falls within his powers of investigation. Autopsies are almost entirely at his discretion. He may interview persons privately but rarely hold an inquest. He usually has the services of his own or police investigators.

This is, therefore, an expert executive system that can deal quickly with a large workload. Although the medical examiner is empowered to investigate a wide variety of deaths, the categories are not, in every case, so wide nor the conduct of autopsies always sufficiently within his discretion for him to remain confidently immune from lawsuit for abuse of his office (2). The inquiry and disposal of the cases are initially private, in the hands of the medical examiner and the police. This represents a considerable concentration of medical and discretionary legal authority in the medical examiner (2).

The organization is usually statewide. The Office of The Chief Medical Examiner, with supporting toxicologic and forensic science services, is likely to be in the largest city and often associated with a university medical school. Similar but smaller offices are in cities elsewhere. In the rural counties, part-time deputy medical examiners who are doctors but not necessarily pathologists refer cases requiring autopsy.

A Chief Medical Examiner is now generally required to be a forensic pathologist. In States in which the system was introduced some time ago, the requirement may be for a pathologist or simply for a medically qualified person (12, 14). Unfortunately, States hoping to introduce a medical examiner system may find forensic pathologists and the necessary finance to be in short supply. Therefore, inadequate coroner systems may exist by default.

Similarly, the nominal existence of a ME system is no guarantee of an efficient medicolegal service. A legal change-over without the appointment of a suitable person as CME, or without adequate funding for suitable staff and premises, does not provide for the adequate investigation of cases (6).

In the event of a civilian light aircraft accident, the likelihood of autopsy on occupants other than the pilot, in the absence of pressure from the Federal Aviation Administration (FAA) or NTSB, is variable. Nevertheless, cooperation by the medical examiner with these authorities or with the military is likely to be very good, depending perhaps on the tact of the visiting flight surgeon. Alternatively, the bodies of military personnel may be surrendered to the military for autopsy, which frequently occurs. (See later section).

The pre-existence of a medical examiner system with a staff of forensic pathologists is of the greatest value in the event of a major disaster. Military aviation pathologists from the Armed Forces Institute of Pathology (AFIP) are unlikely to be called to assist the NTSB if the medical examiner team is sufficiently large to cope with the number of autopsies required.

National Transportation Safety Board

The National Transportation Safety Board, which includes the Bureau of Aviation Safety, is an independent Federal agency within the Department of Transportation of the U. S. Government. Title 14 of the NTSB Regulations (Aeronautics and Space), para 431.2, reads:

"Responsibility of Board.

"a. The Safety Board is solely responsible for the inquiries into all accidents involving civil aircraft, or civil and military aircraft, within the United States, its possessions and territories....

"b....Certain field investigations are conducted by the Federal Aviation Administration acting under authority delegated by the Board...."

Thus, while NTSB may delegate field investigation in certain cases, the subsequent inquiry and determination of probable cause following a civil accident or an accident involving both civil and military aircraft must always remain the responsibility of the NTSB.

The authority of the NTSB in aircraft accident investigations derives from the 1962 amendment to the Federal Aviation Act of 1958 (18). Section 701C, "Accidents Involving Civil Aircraft" states: "In the case of any fatal accident, the Board is authorized to examine the remains of any deceased person aboard the aircraft at the time of the accident, who dies as a result of the accident, and to conduct autopsies or such other tests thereof as may be necessary to the investigation of the accident: Provided, That to the extent consistent with the needs of the accident investigation, provisions of local law protecting religious beliefs with respect to autopsies shall be observed."

It may be noted that the act is permissive only; it applies only to autopsies thought necessary for investigation of the accident, and this fact makes possible a clash of opinion between Federal and local authorities. Nor is there provision for removal of the remains from the local jurisdiction. Finally, religious beliefs must be respected. Therefore, while the Act is of great value, the wording is not ideal.

Elsewhere in the Act, Section 702, dealing with accidents involving both civil and military aircraft, allows participation in the investigation by the military (See below).

The NTSB has headquarters in Washington, D. C. and has 10 field offices located throughout the United States and in Alaska. The field offices investigate general aviation accidents and lesser accidents to air carrier aircraft and give assistance in the event of major air carrier accidents (11).

In the event of a general aviation accident, the cooperation of the local jurisdiction is likely to be required if autopsies are to be conducted with any degree of ease. The Act of 1958 and the 1962 amendment can, if necessary, be invoked, and the services of any pathologist, whether local or a Federal employee, can be contracted by the Federal Aviation Administration (FAA) to perform the autopsy (18). Upon request the FAA will provide pathology and toxicology services to the NTSB (19). Nevertheless, the question of facilities for autopsy, power to remove the body from that jurisdiction, and the delay resulting from any dispute may result in the reconsideration of the necessity for autopsy.

In the event of a major accident, there will nearly always be a decision to use a Washington-based team, and in the meantime, the field office will ensure the security of the accident site in conjunction with the police and local officials. In the event also of major accidents occurring within the USA, the FAA has agreed to provide, if necessary, pathologic and toxicologic assistance (19). The pathologist or pathologists will form part of the Human Factors Group of the Washington-based "Go Team." The group will be headed by one of the Washington-based Human Factors Specialists and may include a pathologist from AFIP, or one of the consultant pathologists to the FAA, as well as the local coroner or medical examiner. Other doctors likely to be included are the regional flight surgeon of the FAA and airline medical director (11). AFIP cooperation is by contract with the NTSB for the provision of assistance in pathology from the AFIP Aerospace Pathology Division (20). In addition, the NTSB is empowered to contract the assistance of any Federal or non-Federal employee required (18).

Federal Aviation Administration

Although the inquiry and determination of probable cause following a civil-aircraft accident is always the responsibility of NTSB, field investigation of certain classes of accidents in which no FAA function seems involved may be delegated to the Federal Aviation Administration of the Department of Transportation (21). These include fatal aerial applicator accidents, fatal accidents of experimental aircraft, and fatal accidents of amateur-built aircraft. In all other civil aircraft accidents involving fatalities, the investigation will be conducted by the NTSB, though normally with FAA participation.

The FAA has its headquarters in Washington, and has ten regional offices in the USA and Alaska, as well as other offices overseas. In an FAA-conducted investigation, ultimate responsibility for investigation of the medical aspects lies with the Federal Air Surgeon in the Office of Aviation Medicine. This function is delegated to the Accident Investigation Board that receives the Regional Flight Surgeon's Accident Report (22).

Following a fatal general aviation accident, the Regional Flight Surgeon is required to obtain the services of an Aviation Medical Examiner (AME) and of a pathologist. The AME is a physician, usually with experience in performing flight physical examinations, who is available on a volunteer basis to assist in such accidents. The FAA has compiled a list of such physicians (Directory of AME's). Pending the arrival of a pathologist, his duty is to make on-scene examination and communicate with the coroner or medical examiner, and, if necessary, the mortician regarding the need for autopsy. In the event of an air carrier accident, the FAA Regional Flight Surgeon is again authorized to order the services of a pathologist who will work with the NTSB Human Factors Group. The autopsy protocol is passed to the Regional Flight Surgeon and on to the NTSB.

If the local medicolegal official is the medical examiner and local law permits autopsy in the circumstances of the crash, it is likely that the cooperation of the medical examiner will be readily obtained in performing the autopsies. Under these circumstances, the expenses of autopsy and of toxicologic or radiologic studies will probably be borne locally. In the event the coroner or justice of the peace is allowed by local law to authorize autopsy and he does so, autopsy may be performed by a local pathologist. Alternatively, one of the consulting forensic pathologists available to the Office of Aviation Medicine of the FAA may be contacted and his travel arranged (22). There are five such pathologists, geographically dispersed in the United States. If authorization for autopsy cannot be obtained from the local officials, then it may ultimately become necessary to invoke the Federal Aviation Act and in those circumstances also obtain the assistance of a forensic pathologist. Costs will be borne by the FAA.

Other than in those classes of accidents in which field investigation is delegated in its entirety to the FAA, help for pathology may be obtained directly by the NTSB by its contractual arrangements with the AFIP (20) or by temporary employment of the personnel required (18). Arrangements exist for the ready interchange of personnel between NTSB, FAA, and the military (24). (See below).

In the event of a civil accident in a foreign country involving a United States registered aircraft, participation by the FAA occurs only after coordination with the NTSB, the US Embassy, and the State Department. If there is an international field office of the FAA in that country and the country is a member of ICAO, participation can be more promptly arranged.

Armed Forces

In certain respects, the Armed Forces seem well placed to organize the medical investigation of aircraft accidents nation-wide. Each of the armed services has a large number of highly trained flight surgeons with a responsibility to take charge of the medical investigation. Armed Forces hospitals, with pathologists, are located throughout the country. The military enjoy the power to dispatch their highly mobile and highly trained personnel to an accident scene at any hour of the clock. In any case, although 80% of all military aircraft accidents occur off base, only very few occur more than 100 miles from the base of origin.

On the other hand, the military have only small numbers of forensic pathologists or aviation pathologists, and they are located predominantly in Washington, D. C., at the tri-service AFIP. While the pathologists of the Aerospace Pathology Division at the AFIP are available upon request to assist at the scene, it would be unreasonable to expect constant nation-wide coverage. In addition, aircraft-accident investigation, including medical investigation, is organized separately by the three armed services, each with its own aviation safety center. At the present time, these centers do not provide pathology services.

Since the hospitals of each service are widely scattered and are not necessarily located adjoining a flying center, easy access of the pathologist to the accident is usually not possible; in any case, he is a hospital and not a forensic pathologist and already has full-time commitments.

The major problem, however, is probably one of jurisdiction. Outside the military base, the military have no jurisdiction and no power for autopsy, even over the remains of military personnel. The flight surgeon is well placed to explain the desirability of autopsy, however, and in those cases in which autopsy is carried out this is frequently done by a coroner's pathologist or a medical examiner with a flight surgeon present to advise on aviation aspects. Commonly also, the bodies are released to the military and autopsy carried out by a hospital military pathologist. In these cases, on-scene investigation by the pathologist is unlikely. In areas with a large volume of military aviation, it is possible, though rare, for agreement to be made between the civil and military authorities that aviation-accident autopsies will be performed by military personnel at the base hospital.

On the base itself, the Federal Government (and so the military authority) may possess different types of jurisdiction in different areas. This situation has arisen because parcels of land were acquired at different times or because some degree of authority has been ceded back to the States. Thus, the Federal Government may have exclusive jurisdiction; or jurisdiction may be held concurrently with the State; or jurisdiction of the Federal authority may be partial; if the Federal authority is proprietorial only, then all jurisdictional authority is held by the State (9).

Clearly, unless the military have exclusive jurisdiction at the accident site, the interplay of military and civil jurisdiction in respect of control over the remains should be understood by both sides as early as possible. The Office of the Judge Advocate General should be consulted prior to autopsy, and if any overlap with the civil authorities seems possible, they too should be consulted.

Authority for Autopsy following Military Aircraft Accidents. The authority of the NTSB for autopsy examination extends explicitly only to those aboard a civilian aircraft at the time of the accident (Federal Aviation Act 1958 Sec. 701c). In accidents involving both civil and military aircraft, the Board provides for military participation (Sec. 702a), and in accidents involving only military aircraft, the military will provide for participation by the NTSB (Sec. 702b). Authority for autopsy of those aboard the military aircraft is not explicitly provided for in these sections.

Lilienstern (9) discusses the limitations of military investigatory jurisdiction. The President is Commander-in-Chief of the Armed Forces and is authorized by a section of the US Code to prescribe regulations to fulfill his requirements in that capacity. Although there is no statutory authority for any particular military regulation issued by the Secretaries of the Army, the Air Force, or the Navy, these regulations are issued on behalf of the Executive and should be regarded as having the effect of law on their respective services (23). However, the provisions vary among the three services.

Army. Title 10, US Code, deals generally with deaths requiring investigation. Para. 4711 reads: "Inquests. (a) When a person is found dead under circumstances that require investigation, at a place garrisoned by the Army and under the exclusive jurisdiction of the United States, the commanding officer shall direct a summary court-martial to investigate the circumstances of the death."

The Judge Advocate General of the Army has given an opinion that the summary court-martial officer is thereby vested with the functions of a coroner, including the right to order autopsies (9). Notably, the section applies to both civil and military persons, but if the Army does not enjoy exclusive jurisdiction, presumably the interplay with State law must be considered.

Army Regulation 40-2, Section 4-4, deals with military personnel on active duty:

"4-4. Autopsy authority or consent.

"a. Commanders may authorize autopsies performed on the remains of members of the military departments who die in the military service, while serving on active duty or active duty for training, as follows:

"(1) When it is considered necessary for the protection of the welfare of the military community to determine the true cause of death or to secure information for the completion of military records.

"(2) When death occurs while the member is serving as an aircrew member in a military aircraft, an autopsy is mandatory."

Only military personnel are covered. This section makes no allowance for jurisdiction and may conflict with the local authority.

The section continues:

"b. In cases not covered in (a) above, when an individual dies in an Army MTF or on a military installation, consent from the spouse or NOK must be obtained, except as provided in (1) or (2) below, before an autopsy is performed.

"(1) If applicable State laws authorize the performance of an autopsy, the commander may order an autopsy performed without the consent of the spouse or NOK.

"(2) In oversea areas where local laws and regulations require an autopsy, and the United States not been (sic) exempted from such laws and regulations by treaty or agreement, the commander will order an autopsy performed without the consent of the spouse or NOK.

"c. In cases not covered in (a) above, when an individual dies outside a military installation and is dead on arrival at an Army MTF, the authority for autopsy is governed by applicable local laws unless the local authority specifically relinquishes such right, in which case the provisions of this paragraph apply."

By implication, Section 4b may refer mainly to civilians, including dependents. While this allows the commander to comply with local practice in authorizing autopsies, the question of jurisdiction remains, unless concurrent jurisdiction is in effect.

Air Force. Title 10, US Code, Para 9711 confers on the Air Force, in precisely the same words as did Para 4711 on the Army, the authority to investigate deaths. In addition, AFR 160-109, "Medical Investigation of Aircraft Accidents," reads:

"2. Investigation. The senior Air Force medical officer of the organization or unit conducting the investigation of the aircraft accident will carry out the provisions of this regulation. He will request the services of the pathologist at the consultant center by the most expeditious means available....

"3. On Whom Autopsies will be Performed. Autopsies will be performed on all deceased aircrew members believed to have been involved in the actual operation of the aircraft (pilot, co-pilot, engineer, etc.), or believed to have been engaged in essential flight activities, (navigators, radio operators, etc.). Also, autopsies will be performed on other personnel aboard the aircraft if the examining medical officer thinks it will help to explain the accident....Collection of tissue and blood from passengers for toxicological studies may be of value in reconstructing the accident sequence."

In this context, the responsibility for obtaining the autopsies is placed with the senior Air Force medical officer (Para 2). Presumably, this same paragraph provides him with the necessary authority. AFR 169-109 does not refer to questions of jurisdiction or to the military status of the deceased. The intent of the Regulation is clarified by AFM 168-4:

"4-39. **Performing Post-Mortem (Autopsy). The authorization to perform a pout-mortem examination** will be filed in the clinical record of the deceased. This may consist of a properly completed SF523, Clinical Record - Authorization for Autopsy, a letter from the base commander, or his designee (b below), or any other documented evidence of authorization. Except in the circumstances described in (a) below, a post-mortem may be performed only with the consent of the surviving spouse, next of kin, person having right of burial, or at the request of the local coroner or medical examiner....

"a. When a Post-Mortem will be Performed. A complete postmortem will be performed on a member of the Armed Forces (called or ordered into active military services for a period of more than 90 days), who dies on an Air Force base, when any of the following applies:

"(1) Death occurred under circumstances suggesting crime, suicide, or other appearances requiring investigation. A post-mortem will not be excluded merely because a superficial examination may suggest a conclusion as to cause of death.

"(2) Cause of death might constitute a menace to public health.

"(3) Cause of (traumatic) death, other than those listed in (4) below, is impossible, without a post-mortem examination, to determine whether physiological or pathological changes may have precipitated the events that led to death.

"(4) Death occurred while the person was serving as an aircrew member in a military aircraft. (Note: Under AFR 160-109, paragraph 3, 17 February 1964, an autopsy should be performed whenever practicable regardless of location of the crash or incident).

"(5) The physician is unable to establish the cause of death.

"(6) Death occurred while the person was confined in disciplinary custody and had not been punitively discharged from the military service.

"(7) When the commanding officer of an installation or command, of his own volition, or upon the recommendation of the investigating officer or other fact-finding body or medical officer deems such procedure necessary to determine the true cause of death; secure information for the completion of military records; or protect the welfare of the military community.

"b. Who Will Authorize a Post-Mortem. The installation commander is the approving authority for most post-mortem examinations required by (a) above. This is true also in overseas areas, including US possessions, where the United States has jurisdiction. Where the United States does not have jurisdiction, appropriate US officials may direct and perform post-mortems if local authorities agree. The installation commander may delegate his approving authority to the director of base medical services. This delegation will be in writing to the DBMS and current at all times.

"c. Performing a Post-Mortem on a Civilian. A post-mortem examination of a deceased civilian is governed by laws of the state or foreign land where the Air Force installation is located. Generally, these laws require the written, signed permission of the nearest relative, or an order by an appropriate civil authority if the death occurred in unusual or suspicious circumstances. Each installation will develop its own procedure, incorporating the requirements of this directive, relevant laws, existing legal agreements, and other legitimate requirements of local authorities. For post-mortem purposes, the remains of members of the National Guard, Reserve Officers Training Corps, and any other Reserve components — ordered to active duty or active duty for training for 90 days or less — will be treated as civilians....

"d. Performing a Post-Mortem on Foreign Military Personnel. Foreign military personnel who were in active military service in the CONUS are included in the provisions of (a) above. However, before an autopsy can be performed, permission must be obtained from the pertinent air attache of the foreign embassy....

"Note:

"....When necessary, a civilian pathologist may be employed and paid from funds available locally under the operation and maintenance appropriations (AFM 160-19)."

The installation commander is therefore allowed to authorize autopsy examination only on military personnel dying on a military base under circumstances considered to require investigation. Under para 4-39b, where the United States does not have jurisdiction the agreement of the local authorities is necessary. This could be understood to include areas of military bases where the military do not enjoy exclusive jurisdiction.

Navy. The naval authorities rarely enjoy exclusive jurisdiction. Naval instructions, which refer also to accidents involving Marine Corps aircraft, strongly recommend autopsies on crewmember fatalities. The flight surgeon in charge of the medical investigation is expected to recommend to the commanding officer that an autopsy be performed (33, 34).

As with the Secretaries of the Army and Air Force, the Secretary of the Navy has been statutorily delegated the authority to administer the Navy (30). Further, he has been statutorily given the power to prescribe regulations, not inconsistent with law, to govern his department (23).

OPNAVINST 3750.6K (Navy Aircraft Accident, Incident and Ground Accident Reporting Procedures), Chapter VII, 703b and 703c, reads:

"b. Pathological Studies in Fatal Accidents. In the event of a fatal aircraft mishap, the investigation is not considered complete without an autopsy study of crewmember fatalities. The majority of these autopsies will be performed in Naval hospitals having pathologists. Other federal or civilian hospitals may be used when Naval assets are not available....

"c. Conduct of Autopsies. The effective BUMED Instruction (6510 series) and Article 17-2, Manual of the Medical Department, in conjunction with the traditional prerogatives of command (Chapter VII, Navy Regulations 1973), and this instruction constitute the authority to perform autopsies on military occupants fatally injured in aircraft mishaps...."

BUMED Instruction (6510 series) refers to the function of AFIP and other Histopathology Centers. Article 17-2, Manual of the Medical Department, in its subsection (1) gives authority for autopsy on military personnel dying in military service without reference to jurisdiction:

"17-2. Autopsies.

"(1) Deceased Military Personnel - An autopsy shall be performed on the remains of any person who dies in the military service while serving on active duty or active duty for training when the commanding officer of his own volition or upon the recommendation of an investigating officer or other fact-finding body or medical officer deems such procedure necessary to determine the true cause of death; to secure information for the completion of military records, or to protect the welfare of the military community. When death occurs while serving as an aircrew member of a military aircraft, the medical officer shall recommend to the commanding officer having custody of the remains that an autopsy be performed to determine the cause of death. Under these circumstances, the commanding officer may authorize such an autopsy. The "cause of death" in this connection is interpreted to mean any correlation between pathological evidence and the accident cause factors."

Article 17-2 (2) requires authority from next-of-kin for autopsy on nonmilitary or retired personnel dying on base, or recourse to civil authority:

"(2) Other Deceased Persons - When an autopsy is deemed necessary for retired personnel or non-military persons who die in a naval medical treatment facility or at a Navy installation, written authorization from the next of kin shall be obtained before the autopsy is performed....If permission is unobtainable, and an autopsy is required to complete records of death in compliance with local, State, or Federal law, a report shall be made to civil authorities for necessary action."

Interpreted in the most restrictive manner, the commander, if he has custody of the remains, may authorize autopsy on military personnel killed on duty.

Cooperation Among Federal Authorities

Ample provision exists for cooperation among the NTSB, the FAA, and the military, both in the use of personnel at the scene of investigation and in exchange of information relating to air safety.

In the following sections of the Federal Aviation Act, "The Board" is to be understood as the NTSB, which replaced the Civil Aeronautics Board in 1966, and "The Administrator" can be understood as the FAA acting on behalf of the Secretary of the Department of Transportation. Section 701.g of the Federal Aviation Act concerns participation of the FAA in NTSB investigations and reads, "In order to assure the proper discharge by the Secretary of Transportation of his duties and responsibilities, the Board shall provide for the appropriate participation of the Secretary of Transportation and his representatives in any investigations conducted by the Board under this Title:

"Provided, That the Secretary of Transportation or his representatives shall not participate in the determination of probable cause by the Board under this title."

Section 702 reads:

"(a). In the case of accidents involving both civil and military aircraft, the Board shall provide for participation in the investigation by appropriate military authorities.

"(b). In the case of accidents involving solely military aircraft and in which a function of the Administrator is or may be involved, the military authorities shall provide for participation in the investigation by the Secretary of Transportation.

"(c). With respect to other accidents involving solely military aircraft, the military authorities shall provide the Secretary of Transportation and the Board with any information with respect thereto which, in the judgment of the military authorities, would contribute to the promotion of air safety."

These provisions for cooperation in accident investigation and inquiry are amplified in a tri-service regulation entitled "Participation in a Military Aircraft Accident Safety Investigation" (23). Para 22 reads, "Interchange of Qualified Investigative Personnel between Military Departments and NTSB and FAA. The president/senior member of a Military Aircraft Accident Safety Investigation Board, the NTSB investigator-in-charge, or the FAA accident coordinator may lend or interchange personnel who are specialists in aviation technical fields, so that proper and timely evaluation can be made of all accident evidence."

There is, therefore, every opportunity for Federal personnel at the scene to function as a single team, whether they be military pathologists or civilian forensic pathologists designated by the FAA or temporarily employed by the NTSB.

UNITED KINGDOM

The development of an aviation pathology service for aircraft accidents occurring in the United Kingdom was helped by the relatively small size of the country and by accommodation of the new aviation pathology service within the existing medicolegal system (8, 9, 13).

The United Kingdom consists of England, Scotland, Wales, and Northern Ireland. England has about 90% of the population of the United Kingdom and is the area where most of the aircraft accidents occur. England and Wales, for most purposes, comprise one administrative area and, like Northern Ireland, have an updated coroner system. In Northern Ireland, only full-time forensic pathologists are employed (7). Scotland has a version of the "continental" system.

England and Wales

The coroner in England and Wales is required to be a doctor or lawyer of at least 5 years' experience. Most are lawyers serving as coroners in a part-time capacity. Many have already served as deputy coroner and were chosen for their experience and interest in the work. In large cities, the coroner is often a full-time official and doubly qualified in both medicine and law. The coroner is employed by the local authority as a life-time nonpolitical appointment subject to the continued approval of the Lord Chancellor, who is head of the legal profession in England and Wales.

The authority of the coroner is considerable and includes the investigation of deaths from accident or uncertain causes. He takes charge of all such cases in his jurisdiction, which may include a military base, and is required to establish the precise medical cause of death and the circumstances in which death occurred. Only rarely will a coroner approve the removal of a body from his jurisdiction. He is the authority for the medicolegal autopsy and is immune from suit in that respect (9). He may choose which pathologist and which laboratory he will use in any particular case and authorize payment from the local authority. He may also call upon any agency or individual to assist him. In his investigation he may hold informal interviews or an inquest--with or without a jury--and subpoena witnesses.

The pathologists normally available to the coroner are hospital pathologists of the National Health Service and forensic pathologists from university Departments of Forensic Medicine. The latter hold the more important Home Office appointments and deal with most of the more obvious criminal cases. Laboratory facilities available as required by the coroner include those of the NHS hospitals and the university, police and Home Office Forensic Science laboratories (3).

In England and Wales it is likely that Her Majesty's coroner would in any case order an autopsy on fatalities resulting from an aircraft accident. Responsibility for autopsy investigation of all fatal aircraft accidents occurring within the United Kingdom or to registered UK aircraft outside the United Kingdom rests, however, with the Department of Aviation Pathology, RAF Halton. This responsibility extends to both civil aircraft and military aircraft of the Royal Air Force, the Royal Navy, and the British Army.

The RAF Department of Aviation Pathology was founded in 1955 (8). The centralization of aviation pathology in the UK in one specialized department provides maximum experience for a small number of pathologists. In addition, it requires the development of liaison between that one department only and the civilian medicolegal authorities. Soon after the formation of the Department, the government Home Office Circular 204/1955 to HM coroners suggested that "in the event of any flying accident involving loss of life, the coroner having jurisdiction might invite the Royal Air Force to provide a pathologist to attend the post-mortem examinations as an observer." A more recent Circular 90/1971, remarks, "when a coroner is called upon to investigate deaths following an aircraft accident, he may wish to consider asking a Royal Air Force pathologist to carry out the necessary post-mortem examination" (9).

No coroner is bound by the suggestions, but they are compatible with the Coroners' Rules of 1953. Rule 3(a) provides that the coroner should, whenever practicable, instruct that the post-mortem examination should be made by a pathologist with suitable qualifications and experience.

Since the formation of the Department, the aviation pathology service has removed no authority from HM coroners or their civilian pathologists. The RAF pathologists have had the necessary support of HM government. A working relationship has been easily established in which the RAF pathologist may advise or perform the autopsies in conjunction with the civilian pathologist and the approval of the coroner. He may also obtain on request the specimens he requires for histologic or toxicologic examination at the Department of Aviation Pathology.

Scotland

The Act of Union of 1707, which united the parliaments of Scotland and England, provided that the Scottish legal system be preserved. Scotland is historically a civil law country and basic differences between the Scottish and English legal systems remain. The Scottish court system and the Scottish system of medicolegal inquiry follow the continental pattern.

Deaths thought to require investigation, including those resulting from fatal accidents, are reported by the police to the Procurator Fiscal ("public prosecutor"), who, with the police, is responsible for an initial inquiry. The Procurator Fiscal is a lawyer, a member of the Judge Advocate's Department, and not a doctor. His duties are not confined to medicolegal work.

In his initial inquiry, he may be prepared to accept medical evidence of the cause of death based upon external examination only. If he feels that an autopsy examination is necessary, he is obliged to petition the Sheriff to issue a warrant for a full post-mortem examination. He must similarly petition the Sheriff if he feels that the latter should hold a public inquiry (13).

This procedure involves a certain delay, and if the Procurator Fiscal is unwilling to request authority for autopsy, there is no recourse other than to approach the relatives for permission. If authority is obtained, autopsy is carried out in cooperation with civilian pathologists. As in England, the pathologists and laboratory facilities available are those of the National Health Service Hospitals or University Departments of Forensic Medicine.

TABLE

Simplified interpretation of the present status of autopsy authorization following aircraft accidents in the United States. Modified from Ballo (35).

I. CIVIL AIRCRAFT

Crash occurs on a --	Civilian area	*Military area
and the fatality is —	(1) Military	
Then --	NTSB may order autopsy.	Base Commander or NTSB may order autopsy.
	(2) Civilian	
	As above.	US Army or US Air Force Base Commander or NTSB may order autopsy. On US Navy bases, permission from next of kin or civil authority is required.

II. MILITARY AIRCRAFT

Crash occurs on a --	Civilian area	*Military area
and the fatality is —	(1) Military	
Then --	Local civil authority controls disposition of the bodies.	Autopsy may be performed under military regulations.
	(2) Civilian	
	As above.	US Army or US Air Force Base Commander may order autopsy. On US Navy bases, permission from next of kin or civil authority is required.

*Assuming the military has exclusive jurisdiction.

CONCLUSIONS

Since aircraft accidents occur unpredictably and sometimes in rapid succession, it would be difficult for a government to guarantee the provision of aviation pathologists to deal with all fatalities. Although this has been nearly achieved in the United Kingdom, the situation is more difficult in the USA, where the geography and the volume of aviation make greater demands.

It would be unwise, therefore, to attempt to remove a responsibility for these cases from the local jurisdiction. Where the local system of forensic inquiry is professionally staffed, cooperation has been readily obtained and the local expertise has been of great value to the aviation pathologist and flight surgeon.

There remain those instances in which autopsy investigation is delayed or refused. In the USA, legal difficulties are most likely to occur in the particular rural areas where an ineffective coroner system persists, while in urban areas Federal involvement has occasionally caused hostility. Despite the Federal Aviation Act, such lack of cooperation may be a grave handicap in both civil and military cases. Of very great value would be permissive authority to the military for the autopsy of victims of military aircraft accidents, comparable with that already granted to the NTSB in the case of civil accidents. This, in conjunction with explicit provisions for removal of the remains to premises considered adequate and convenient for the Federal investigators, would give the NTSB and the military investigators the authority they require.

In the United Kingdom, problems have been considerably less. The Scottish "continental" system is a potential cause of inconvenience, since authority for autopsy lies with the Sheriff, who is not directly concerned with the initial inquiry. An arrangement such as exists in England and Wales, whereby the head of the legal profession presumes that autopsy examination will be performed and encourages the participation of the Royal Air Force pathologists, might be sufficient to prevent occasional difficulties.

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DISCUSSION

McMEEKIN: What do you believe is the solution to problems of jurisdictional conflicts in aircraft-accident investigations?

CHRISTIE: I do not anticipate any easy or permanent solution in circumstances where both federal and local authorities have a responsibility for investigating such deaths and where the prerogatives are constantly changing. In the case of civil accidents in the United States, I suspect it may be possible for the NTSB to make liaison with State authorities in advance of the occurrence of an accident to ensure that cooperation will be forthcoming or that NTSB authority will be recognized by the State.

In the case of military accidents, a military version of the Federal Aviation Act as described in the conclusion of my paper seems appropriate. In the meantime, prior arrangements with State authorities in the areas surrounding military bases with a high volume of flying, at least to allow an aeromedical presence at the autopsy, would be of value. Surrender of the body to the military, when that is legally possible, would, of course, be more satisfactory.

McMEEKIN: Do you have any recommendations regarding release of investigative findings?

CHRISTIE: I assume you refer to autopsy findings of civilian pathologists on remains of military personnel in the United States. I believe that release of such information may be restricted by local statutes, and these vary widely among different jurisdictions. This is not a problem with which I intended to deal, and I cannot claim any special knowledge on which to provide an answer should you be obliged to deal with an uncooperative medical examiner, district attorney, etc. These officials may, of course, be restricted by their local statutes in spite of a willingness to cooperate.

KNAPP: What are the international provisions for recovery of bodies after loss of military aircraft over territory outside the country of origin?

CHRISTIE: I did not attempt to deal with the questions of recovery of the remains of personnel from overseas, in the sense of repatriation. That and questions of autopsy would, legally, involve status-of-force agreements and, in practice, the question of civil or military jurisdiction at the accident site. In the United Kingdom, in practice, the coroner readily surrenders remains of United States military personnel to your authorities.

KNAPP: How does one handle the examination of bodies from a fatal aircraft accident in which multiple nationalities are involved?

CHRISTIE: With civilian accidents involving a foreign registered aircraft, member countries subscribe, at least in theory, to the procedures described in my paper, particularly references 15 and 16. You will note that the country of registration has rights, but the country of nationality of the deceased does not. I recommend P. J. Stevens' paper in Aerospace Medicine of, I think, 1967, dealing with problems of civilian accidents overseas, which, interalia, describes local problems at the accident site and the United Kingdom's method of dealing with identification and repatriation.

EWING: It should be pointed out that in law, ownership of the remains of naval personnel on active duty at time of death resides in the U.S. Government. As a matter of courtesy, the next of kin are usually requested to permit an autopsy to be performed, but this is not legally required. As a matter of practice, military authorities may, by regulation, waive their rights under this law, but such waiver can be cancelled simply by altering this regulation.

CHRISTIE: I take the point that the Federal Government may claim ownership of these bodies, but this need not imply the right to remove the remains from the local jurisdiction or to authorize an autopsy or the performance of an autopsy. Naval personnel may risk suit for so doing, and they may also find themselves in conflict with the civilian jurisdiction. My references 31 and 33 are the authority for Navy personnel, and the precise wording is binding upon them. It may be of interest that AR 40-2, Section 4-4, and AFM 168-4 concede the authority of the local jurisdiction, even in the case of military personnel, on whom they do not hold exclusive jurisdiction. Where the Navy enjoys exclusive jurisdiction there is no problem.

MEDICO-LEGAL PROBLEMS OF FLIGHT ACCIDENTS INVESTIGATION

by

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SUMMARY.

Necessity is premised of close collaboration between the specialist in forensic medicine and the flight surgeon, in flying accidents investigation.

These accidents are surveyed in their different types, various traumatic mechanisms and possible correlations existing between physio-psychical conditions of flying personnel and genesis of single accidents.

Different body lesions, sustained by victims of flight accidents, are deeply examined. They are divided into lesions pertaining to skeleton, internal organs and external teguments ; and pathogenetic interpretation of each injuries is discussed.

As conclusion, reconstruction of causes and ways of flight accident production is discussed. This can be possibly carried out through the examination of differential characteristics of various traumatic findings of the different types of accidents, considering kinedynamics of the single accident as well as the phase in which the injuries were sustained (precipitation, or explosive decompression with subsequent precipitation, or impact on the ground followed by an explosion or not, or explosion in flight followed by impact, or finally the terminal fire on board with or without inhalation of smoke or toxic gases).

From this reconstruction useful elements can be obtained, for the prevention of flight accidents and dependant injuries.

INTRODUCTION.

In today's approach to investigations connected with flying accidents, close collaboration between the flight surgeon and the specialist in forensic medicine is particularly opportune and necessary. The study and identification of the causes of air disasters and the ways in which they take place is, in fact, of considerable importance not only for the purposes of ascertaining any penal, civil and disciplinary responsibilities in the production of the individual accident, but also - in a wider perspective - for the purposes of making the prevention of flight accidents more effective and keeping the death toll as low as possible.

In the framework of this necessary collaboration, the principal task of the flight surgeon is obviously to seek and pinpoint the causes of flight accidents connected above all with the human factor.

It is well-known, in fact, that the possible causes of flying accidents are, in order of frequency : causes connected with the human factor ; technical causes, due to the inefficiency of the machine ; meteorological causes, due to particularly adverse atmospheric conditions (which may also have an unfavourable effect on the conditions of the ground or the water in which the take-off or landing on land or water takes place) ; accidental causes, unforeseen and concretely unforeseeable ; unknown or undetermined causes ; the concurrence of several causes.

As for the human factor, flying accidents are generally caused by the flying personnel responsible for the control of the aircraft in flight or, more rarely, by the ground personnel, responsible for the maintenance and for checking the maintenance of the aircraft or for flight assistance and air traffic control.

The most frequent causes for which the pilot, on his side, may cause a flight accident are : <u>professional causes</u> (because of deficiency of aptitude, inexpertness, imprudence, insufficient training, negligence in carrying out flying duties or in the observance of rules and regulations, manoeuvre or navigation errors, etc.) ; <u>psychical causes</u> (because of imperfect or inadequate articulation of the superior psychic processes : for example, errors of evaluation or judgment or interpretation or perception) and <u>behavioural causes</u> (because of characterological deficiency, for example indiscipline in flight ; because of carelessness, inattention, indecision, etc.) ; <u>causes bound up with the physiopathological effects of flying</u> (hypoxia, low pressure, aeroembolism, explosive decompression, accelerations, vibrations, abnormal variations in the attitude of the aircraft, kinetosis, variations of temperature, illusions in flight, dizziness and disorientation in flight, flying fatigue, intoxication from toxic substances in the flying environment such as carbonic monoxide, fuel vapours, etc.) ; <u>generic physio-pathological causes</u> not specifically connected with flying (improper diet, qualitatively or quantitatively ; lack of rest and a regular pattern of life; intoxications from drugs or alcohol or smoking or

other toxic or voluptuary substances ; sudden and unforeseeable accidents of vascular or nervous origin or of any other nature, such as myocardial infarction or angina pectoris, stroke, visceral colics, epileptic attacks, etc.).

The ground personnel, in turn, can be the cause of accidents whenever their working fitness is diminished by the most varied causes, such as common acute or chronic illnesses or some particular illnesses specifically bound up with the environment of work (intoxications, tiredness), or by the failure to apply, or inadequate application of, occupational health norms (such as, for example, the norms concerning the illumination of environment of work, protection from heat and cold, from toxic substances, acoustic traumas, vibrations, etc.) or, finally, because the personnel is unfit for the work in which they are engaged, because of negligence and errors in the overhauling and maintenance of aircraft on the ground or in air traffic assistance and control, etc.

In the course of the medical investigation about flight accidents, it is obviously not easy to pick out and evaluate the various physiopathological causes, or causes connected in some way with the human factor, which may have caused, or contributed to cause, the accident. It is evident at this point how important it is that the competent and expert work of the flight surgeon should be accompanied and completed by the intervention of the specialist in forensic medicine, so that their joint and expert work may make it possible - through the evaluation of the results of the examination of the remains of the victims and the crashed plane - to seek and identify the causes of air disasters and the ways in which they took place.

In this case exact knowledge of the correlations that exist between the type and the importance of the various traumatic injuries and the biodynamic causes that may have produced them, is very important for the purposes of the exact reconstruction of the ways in which the injuries were produced and the traumatic mechanisms involved. This reconstruction calls for the correct and careful application of general and particular notions on the causes of injuries, since in most cases there are found in the same subject effects produced by multiple damaging actions and multiform traumatic mechanisms, such as violent impact, explosion, compression, decompression, the action of flames or heat etc., as well as effects produced by the intervention of damaging or destructive factors such as the traumatic sphacelation of bodies as a result of precipitation or impact against solid or liquid surfaces, carbonization as a result of the explosion of bits of the aircraft or of fuel vapour or of the fuel itself on contact with the ground, the further injuring actions of external or atmospheric agents on bodies floating in the sea or exposed to the external environment before they are found, etc.

In all these evantualities it is evident how indispensable is the intervention of the expert in forensic medicine, who has the task of carrying out the investigations on the spot, making the necroscopic examination and if possible identifying the victims of the crash, and taking viscera and fragments of tissues from the corpses for the toxicological and histological examination, in order to be able to trace - through study of the injuries - the means that may have caused them.

PARTICULARS AND TRAUMATIC MECHANISMS OF THE VARIOUS TYPES OF AIRCRAFT ACCIDENTS.

Various definitions have been proposed to indicate and define flying accidents. A definition that seems to us sufficiently satisfactory could be the following one : "by flying accident" is meant "all events resulting in damage to the plane, persons or things, derived from use of an aircraft during one or more flight phases".

By flight phases are meant the parts of which a flight is composed, from the moment when the propelling organs of the aircraft are started and there begins the movement of the latter in order to take flight, until the moment when these organs and the aircraft stop after the flight itself. The flight phases are, therefore : taxiing before take-off after starting, take-off, flight, landing, taxiing after landing until the plane stops in the parking area and the engines are turned off.

Flying accidents can be classified in various categories, according to their seriousness, the flight phase in which they take place and the dynamics of the accident itself.

As regards the extent and seriousness of the damage, accidents are considered serious if one or more persons are mortally or seriously injured and/or if the aircraft is declared out of use and/or there is serious damage to things ; they are classified as slight if one or more persons are slightly injured and/or if the aircraft is declared repairable and/or there is slight damage to things.

As regards the flight phase, in general flying accidents take place less frequently during the actual flight and more frequently, on the contrary, during the so-called "critical phases" of the movement of the aircraft, that is, during the phases of passing from one operation to another (transition from motion in the air to motion on land-water surface and viceversa).

The most frequent accidents during taxiing, and particularly during take-off and landing are : collision with obstacles, skidding, vertical position, overturning, stall at low altitude, violent landing, boom. These accidents can generally be analysed in

quite a complete and exhaustive way both from the kinedynamic point of view and as regards the injuries derived from them, and so they give rise only rarely to particular medico-legal problems.

In general, accidents that take place during actual flight are far more serious and complex. They usually consist in fall or in collision in flight with one or more aircraft, with subsequent fall ; to these should be added, especially for military aircraft, parachuting with or without ejection seat.

These accidents which take place during flight cannot always be analysed in an equally satisfactory way, since the injurious effects due to them are often partly or completely distorted and masked by the superimposition of further injurious effects due to the impact of the aircraft and its content upon the surface of the ground or the water.

Finally, as regards the injuries, there is great variability of the traumatic injuries met with in the various types of accidents both as regards the importance of the injuries and as regards the organs and regions of the body affected, these factors being closely linked with the kinedynamics of the accident.

Obviously, in the less serious accidents, such as violent landing, overturning, skidding, collision with the ground, falling from a very low height, the injuries in question are usually not very serious, and therefore not mortal. Their position and importance is generally correlated with the direction of the field of forces at the moment of the accident and with the speed of the aircraft, which is usually not very high in the flight phase in question, as these accidents occur mainly in landing and take-off.

The traumatic injuries caused by these not serious accidents consist of bruises, bone fractures, dislocations, superficial or deep wounds : occurring most frequently in the head and limbs. If a fire has broken out aboard, more or less diffused and more or less deep burns may occur.

Also in accidents due to parachuting with or without ejection seat, the injuries, if any, are not usually very serious, consisting usually of superficial wounds - bruises and abrasions - sometimes of fractures particularly of the lower limbs or, especially in the case of parachuting with ejection seat from an aircraft at high speed, of vertebral fractures, mainly amyelonic (ROTONDO, 1963,37 ; 1966,39 ; 1975,42) and of injuries due to the aerodynamic pressure of the wind (injuries due to windblast, flailing, tumbling and spinning), consisting generally of superficial injuries such as bruises, or in bone injuries such as fractures, sprains or dislocations (ROTONDO, 1975,43). In any case these injuries are hardly ever mortal, except in cases of unassisted escapes from a very low altitude or of the failure of the parachute to open or delayed opening, in which injuries due to precipitation obviously prevail.

The aircraft accident with the highest death rate is the one in which the plane falls from an altitude that is not low, with the consequent violent impact on the ground or water ; in this type of accident there are nearly always very serious injuries which, as they frequently occur in the head and trunk, cause death in a very high percentage of cases.

The seriousness of the body injuries is due obviously to the high deceleration forces developed in the fall and particularly in the impact ; in fact, when a plane falls, considerable deceleration values are reached. It is often difficult to pinpoint them and their field of action as regards the bodies of the occupants of the aircraft, since the falling plane may strike the ground with its nose, wing, belly, tail, back, etc.; furthermore the speed and the altitude of the plane before the fall vary a great deal, and are often unknown or difficult to state precisely.

But for a more precise evaluation of the body injuries, it is necessary to keep other parameters in mind, in addition to the values and the field of action of the deceleration forces produced in the fall and impact, namely the duration of the application of these forces, their direction, the axis of the body according to which they act, the area of the surface of the body on which the forces are applied, the G/sec. values, etc.

Another type of accident which is often very serious is collision, especially if it occurs in flight. In this kind of accident, too, the direction and amount of the forces acting on the aircraft and on the bodies of the persons on board, are not constantly foreseeable and ascertainable, since the ways in which the impact takes place vary a great deal, as does the seat of the injury. In view, however, of the high percentage of head injuries, the death rate is rather high and it becomes even higher when the collision takes place in flight, at high altitudes ; in this case, to the body injuries due to the collision of the aircraft (during which high deceleration values are obviously reached owing to the summing of the speeds of the two or more planes that have collided), must be added the injuries due to explosive decompression and the ones caused by the fall, that is by the impact (vertical deceleration) of the bodies on the ground or water.

The mortality in these cases reaches extremely high percentages owing to the serious and multiple injuries that are caused.

AVIATION ACCIDENT PATHOLOGY AND PATHOGENETIC MECHANISM OF THE VARIOUS BODY INJURIES DUE TO AIRCRAFT ACCIDENTS.

In serious aircraft accidents the spectacle of the injuries that occur is, as everyone knows, a tragic one : it is a question in general of broken and shredded parts of the body and organs, often reduced to minute fragments, which are hurled over a radius of hundreds of feet by the great forces that develop at impact on the ground, which in the last analysis constitutes the final phase of every air accident. Not infrequently fires break out which reduce the bodies to ashes.

A) Skeleton injuries.

The most common injuries are skeleton ones. Apart from cases of complete disintegration, which occur almost exclusively in the bodies of victims that fall together with the aircraft and remain inside after the collapse of the structures of the cockpit, the bones most frequently fractured are the skull bones, both at the base and at the top (in many cases to the extent of more or less complete decapitation), sometimes the face bones; often there is a loss of cerebral substance.

This greater frequency of cranial fractures in serious aircraft accidents as compared with other skeleton fractures that recur in air crashes, depends above all on the greater mass presented by the head as compared with the other organs of the human body, and therefore the greater weight and the consequent greater kinetic energy it acquires during the violent movements caused by the sudden accelerations and decelerations that generally occur during the accident, and on the great mobility and range of head movements. The latter, in fact, owing to its free articulation on the cervical column behaves like a pendular mass the movement of which cannot always be controlled by the neck muscles if strong accelerations or decelerations are impressed on it. Then, too, the head is covered by a layer of soft tissues that is not very thick and in air accidents it generally strikes structures of the aircraft that have sharp or angular surfaces, so that the maximum concentration of local efforts is obtained.

As for their pathogenetic mechanism, skull fractures can be divided (FORNARI, 1955, 11) into "blast" fractures and "deflexion" fractures. The former, due to changes in the shape of the skull, which behaves like an elastic sphere as a whole, occur in cases in which a bilateral compression is exerted such as can be effected when a body with a large surface, with a considerable kinetic energy, strikes the skull which is fixed to a counter support in the area opposite the one hit, or when the skull (as happens in precipitation) knocks against a resistant surface, thus remaining compressed between two poles, one constituted by the area of contact with the plane of impact, the other lying in the opposite area at the point of application of the force of gravity.

Deflexion fractures, on the other hand, are determined by a one-sided traumatizing force acting upon a limited area.

Bone fractures also occur very frequently in the spine, particularly in the dorso-lumbar and cervical regions, and especially in the low thoracic region and the high lumbar region.

Obviously the traumatic causes of these vertebral injuries are nearly always multiple and multiform, since they can combine with one another and vary according to the dynamics of the accident. However, in accidents that conclude with a violent impact, which are the most common ones, the most important pathogenetic causes are the forced bending of the rachis, with possible torsion of the trunk, and the compression of the vertebrae from above or more often from below. To these factors, which are the two essential components of the mechanism of fracture of the vertebrae by indirect trauma, other mechanisms can of course be added, such as direct trauma on the region of the back, the violent displacement of the body or parts of it against the structures of the aircraft as a result of failure to use the safety belts or if they break, etc.

The other segments of the skeleton in which fractures generally occur are in order of frequency : the ribs and pelvis ; the sternum, injury to which is the result of the violent flexion of the neck and is important owing to the lethal effects it may have on the heart below it ; the limbs, injuries to which may vary from more or less complete amputation to multiple displaced or comminuted fractures of the various segments, particularly femur and humerus, and they are generally caused by their violent displacement against the structures of the cockpit at the moment of the impact.

As regards the thorax in particular, seriate rib fractures are quite often met with, often associated with multiple sternal fractures. The presence of these fractures is proof of a violent succussion and compression of the rib cage especially in its antero-posterior diameter ; it is a question, that is, (FORNARI, 1955,11) of injuries that can be attributed to a trauma directly applied by large wounding surfaces that have suddenly and simultaneously come into contact with several ribs, producing, despite their elasticity, fractures along the same lines, so that they take on the aspect of "seriate" fractures, according to the appropriate definition which designates just this arrangement "in se

ries" of the individual fractures.

B) Injuries to internal organs.

Among the injuries to internal organs that occur most frequently and nearly always play a preponderant role in causing the death of the victims of accidents, mention should be made in the first place of injuries to the brain and to the heart, the aorta, the lungs and the liver.

Brain injuries, which may reach complete sphacelation of the encephalic lobes and of the whole encephalon, are generally accompanied by serious cranial fractures and are the most frequent cause of death in cases of head traumata.

Brain lacerations are often associated with intracranial haemorrhages ; it is rare, on the contrary, to find only intracranial haemorrhages, not associated with brain lacerations caused by external forces ; to the latter occurrence belong the rare cases in which there is survival for a few hours, whereas injuries to the brain and meninges are usually fatal immediately, in view of the extreme violence of the forces generated in accidents involving modern aircrafts with their high speeds.

Injuries to the heart and the aorta are also frequent. Sometimes there are lacerations of the anterior wall of the pericardium with haemopericardium or just endocardiac lacerations without breaking through the whole thickness of the myocardiac wall ; more often complete rupture of the heart can be seen, particularly of the atria (the right one especially) and of the cardiovascular peduncle.

These ruptures of the heart and aorta are to be attributed to the concurrence of several mechanisms of injury : the penetration of fragments of fractured ribs or sternum, direct contusion or concussion of the heart and the large vessels, bursting as a result of compression between the sternum and the vertebral column, traction and laceration of the thoracic viscera (as in traumata due to precipitation) or displacement and torsion of the organ owing to sudden deceleration, sudden increase in the blood pressure caused by compression of the organ as a result of the crushing of the thorax, bursting as a result of a hydrodynamic trauma transmitted.

If the mechanism of explosive decompression has also intervened, ecchymotic haemorrhages can be observed particularly in the subendocardic area and, histologically, marked fragmentation of the myocardiac fibres. In this case the sub-endocardiac haemorrhages are probably due (ROTONDO, 1953,36 ; 1964,38) to the violent wave of pressure starting from the lungs overdistended by the sudden expansion of gases and transmitted to the large vessels and to the heart. If this wave takes place, for example, during the ventricular systole, it may be superimposed on the pressure which is already acting on the endocardium, damaging it with a real contusive mechanism. Transversal fractures of the myocardiac fibres, completely analogous to the ones described by CLEMEDSON (1949,3) in air blast injuries, may in their turn be due not only to the possible sudden liberation of intracellular gases and to the above-mentioned sudden wave of high blood pressure caused by the increased endothoracic pressure, but also and mainly to the wounding action of the shock wave which, generated in the moment of explosive decompression, hits the whole organism, spreading through the intrapulmonary gases and the large thoracic vessels even as far as the heart.

Injuries to the pleurae and the lungs are very common ; in most cases pleural lacerations with haemothorax can be observed and, as regards the lungs, in addition to wide lacerations areas of acute emphysema alternating with atelectasic areas and intraparenchymatous haemorrhages, which may be very extensive to the extent of giving rise to hepatization of whole lobes and extensive haemorrhagic padding.

These pulmonary injuries are most often due (FUCCI, 1955,15) to a violent compressive action, applied over the whole area of the trunk generally in the antero-posterior direction (or viceversa), the effects of which are often heightened by the displacement of abdominal viscera into the thoracic cavity as a result of the concomitant and frequent vast lacerations of the diaphragm. Another traumatic mechanism that can play a predominant role in the genesis of pulmonary injuries is constituted (FORNARI, 1955,11) by the violent succussions of the lungs against the thoracic walls, which on their side have been under stress to drawn nearer, thus tending to straighten the curves of the pulmonary areas to the point of overcoming their elasticity. In many cases, furthermore, it is the sharp fragments of ribs that break the parenchima, giving rise to more or less ample pulmonary lacerations.

It should not be forgotten, finally, that in the genesis of pulmonary injuries other aetiopathogenetic mechanisms may intervene, such as explosion, explosive decompression, the impact of bodies upon the land or water surface, etc.

In particular, air blast injury, which may occur as the result of the explosion in flight of bombs placed on board the aircraft for the purpose of sabotage or as a result of the explosion of the fuel in contact with the ground, takes on the form of pleural and pulmonary lacerations, acute and atelectasic emphysematous phenomena, as well as (if it is a question of vital injuries, not ones inflicted after death) phenomena of congestion and

parenchymal haemorrhage, often assuming the aspect of typical haemorrhagic rib markings. Also pulmonary injuries due to explosive decompression consist mainly in acute more or less diffused emphysema with alternating areas of atelectasia, intense hyperaemia and congestion with notes of pulmonary oedema, haemorrhages of varying seriousness and extension, varying in the different cases from a little rash to large ecchymotic stains, more or less spread over the whole pulmonary area, but generally more often in the diaphragmatic lobes, especially at the costo-diaphragmatic and costo-mediastinal sinuses. Sometimes (ROTONDO, 1953,36) the bleeding takes on a particular configuration, in the shape of haemorrhagic subpleural streaks, arched in form and parallel with one another, which seem to follow the projection of the ribs on the pulmonary surface and are real "rib markings", similar to the ones just described as typical of air blast injury.

As for their pathogenesis, these pulmonary injuries resulting from explosive decompression are generally produced with a triple mechanism (ROTONDO, 1953,36 ; 1964,38) : on the one hand the pulmonary tissue is violently pulled from inside towards outside, that is, against the thoracic wall : a) by the sudden increase in intra-pulmonary pressure, due to the violent expansion of the endopulmonary gases produced at the moment of the explosive decompression and which, through the considerable and sudden distension of the alveoli, is responsible for the acute emphysema and the lacerations of the alveolar septa ; and also b) by the first phase, the negative one, of depression of the shock wave, produced by the decompressive explosion ; this negative wave acts with a real mechanism of suction, sucking the pulmonary tissue already in expansion up towards the outside ; on the other hand, against these two factors, acting separately but synergically, acts c) the second phase, the positive one, of pressure of the explosive shock wave, with a mechanism of contusive impact against the thoracic wall, of which the ribs particularly are pushed forcefully against the lungs. The latter, therefore, subjected to such violent stress in opposite directions, are more or less seriously damaged, presenting changes prevalently traumatic in character, with the rupture of dilated capillaries and alveoli ; these changes are, therefore, in the last analysis, the consequence of the sudden application of pressure to the alveolar walls, which are damaged both because of their own initial resistance to the wave of pressure and because of the crushing of the pulmonary tissue against the more rigid thoracic wall (with a mechanism, therefore, similar to the one proposed by Zuckerman for air blast injury, with the difference that in explosive decompression the positive wave develops from inside the lungs).

Finally, pulmonary injuries very similar to the ones caused by explosions or by explosive decompression can be produced as a result of the impact of the bodies against the land/water surface ; it has been in fact proved by STEWART et al. (1955,53), who catapulted guinea-pigs at varying speeds of incidence on a water surface, that the impact with the water of a body falling at free fall speed can cause the propagation of a shock wave inside the thorax, with diffused pulmonary concussion and the production of injuries of the air blast type, such as confluent subpleural haemorrhages sometimes assuming the form of rib markings, traumatic emphysema arriving at the point of cavitation, atelectasia, haemorrhagic consolidation of whole pulmonary lobes, etc.

In view of the close analogy of pulmonary injuries caused "intra vitam" by explosive decompression and impact with the surface, water particularly, it may sometimes be very difficult or even impossible to distinguish between these injuries. It is not so difficult, on the other hand, to distinguish them from similar pulmonary injuries caused by the explosion of bombs. As this explosion takes place, for example, in a small space such as the fuselage of an aeroplane, it would not just cause injuries determined by pressor imbalance due to the "blast" of the explosion, but would strike the bodies of the victims with splinters of metal coming from the fragmentation of the envelope of the bomb or with splinters acting as secondary projectiles, coming from the metallic parts of the cabin directly concerned in the explosion. In similar cases it is in fact exceptional not to find fragments of metal driven into the bodies of the victims and skin burns caused by the flame of the explosion (the production of heat caused by the explosion in a small space causes, in fact, with the flame which it produces, burns - even to the point of carbonization - of body areas and singeing of piliferous formations).

Of the endoabdominal organs, the ones most frequently injured are the liver and the spleen, which generally present very serious injuries and are sometimes completely reduced to a pulp.

As regards the liver, ruptures of varying size, seat and depth are, in particular, nearly always met with. These range from subcapsular diaereses to sagittal or transversal linear lacerations found particularly on the convex face, less often on the lower face of the organ ; sometimes there are central ruptures of the liver and in some cases it is reduced, as has been said, completely to a pulp.

Also these injuries to the liver are caused (FORNARI, 1955,11) by the intervention of different traumatic processes, such as, for example : percussion, violent compression of the organ, stretching and torsion of its peduncle, and indirect traumata such as counterblow actions, strong tensions of the hepatic ligaments, the sudden violent contractions

of the muscles of the abdominal wall which push the liver against the spine or against the ribs. In this way forced modifications of the curvatures of the liver are brought about with the bursting of a part of it when the tension reaches its maximum.

Among the mechanisms of injury, the most frequent one, however, is a compression action exerted in an antero-posterior direction, that is, applied to the thoraco-abdominal wall. This mechanism seems to agree both with the theory of Krogius (who to explain transversal ruptures of the liver and other parenchymatous organs referred to the laws that regulate bone fractures due to bending, while as regards sagittal ruptures he refers to the geometric laws of the deformation of spherical or oval bodies subjected to bipolar compression), and with the theory of Rosner, who takes into account also the "evasive movements" in a cranial or caudal direction made by the liver driven by the force compressing it.

If the mechanism of explosive decompression has also intervened, there can be observed in the liver, in addition to lacerations in limited or large areas, also considerable passive congestion with subcapsular haemorrhages and, histologically, typical cracks (ROTONDO, 1953,36 ; LALLI and PAOLUCCI, 1958,18), which look like real crevices, often extracellular but sometimes also intracellular, containing overflowing blood cells within them.

The origin of these typical parenchymal cracks, as well as of the numerous macro- and microscopic haemorrhages, can be explained (ROTONDO, 1953,36 ; 1964,38) by admitting that explosive decompression causes under certain conditions, as a result of the shock wave to which it gives rise, a real bursting mechanism of the various organic structures; in fact, if the tissues are subjected to explosive waves having such a great mechanical energy that their breaking point is reached, the structure would cease to resist and would break. These harmful effects depend, of course, not only on the greater or lesser violence of the explosion but also on the physical properties of cohesion, compressibility, elasticity, density, fixation, inertia and frequency of oscillation of the various organs.

But the parenchymal cracks described above may be caused not only by the above-mentioned bursting mechanism but also, perhaps, by the rapid vibrations of the intracellular gases, particularly nitrogen, released violently among the tissues as a result of the extremely rapid decompression. In fact, even if recompression takes place immediately afterwards and these gases return immediately to solution in the tissues themselves, the violence with which they are released and expand in the moment of the rapid reduction of pressure could be sufficient to overcome the force of cohesion and the elasticity of the organic structures and to produce these microscopic breaks.

This hypothesis, which I formulated in an earlier work (ROTONDO, 1953,36), is confirmed by the results of SCHUBERT's researches (1951-52, 46), who found at the histological examination, in individuals who had died as a result of air emboli and in experimental animals (rabbits, dogs) into whose arteries he had injected air, evident "crack spaces" ("Spalträume" and "Aufspaltung") in the heart, the kidney, the liver, the encephalon, the thyroid, etc., as perivasal gaseous gloves and other manifestations of aeroembolism.

Similar injuries to the hepatic ones are found in the <u>spleen</u> ; also these injuries, which range from multiple lacerations to complete reduction to pulp, are to be attributed to the combined action of direct traumata due to compression and of displacements in the cranial direction, in view of the frequent concomitance of lacerations in the hemidiaphragm above it.

Lacerations are met with quite often in the <u>kidneys</u> too, nearly always in the hilum, in a transversal direction and affecting the pelves. These injuries are probably caused (FUCCI, 1955,15) by a force acting in the antero-posterior direction, which, acting particularly on the renal poles, tends to impel them to move backwards and sidewards, while the middle part of the organ is held back by the vascular peduncle. In this way, as the normal curvature of the kidney straightens, it might tear transversally at the level of the hilum, affecting the pelvis at the same time. Nor can the hypothesis be excluded that the kidney, as the result of a sudden deceleration, may undergo shifts and torsions on the peduncle, such as to cause real lacerations.

Injuries to the <u>intestines</u> are met with very frequently. They consist in ruptures of intestinal loops with the diffusion of fecal matter in the abdominal cavity, in which the presence of considerable quantities of blood can often be noted also. This hemoperitoneum is mostly the consequence of the ruptures of the hepatic and splenic parenchymas and is the expression of the hydrodynamic imbalance that has taken place in the circulatory system with a flow of sanguine masses, violently pulled, towards some areas, particularly abdominal ones.

Lacerations are also frequent in the <u>mesentery</u> of the ileum ; the mesentery of the colon, on the other hand, is generally spared. These lacerations are due to contusions or to tangential forces exerting a lacerating action ; in their turn intestinal ruptures

are generally the result of the application of considerable crushing forces or are the expression of a violent deceleration to which the whole body has been subjected.

C) Skin injuries.

Finally as regards skin injuries, quite often a great disproportion can be observed (FUCCI, 1955,15) between the numerous and often impressive skeletal and visceral injuries and injuries to the external teguments. Although the latter are nearly always subjected to intense direct contusing actions, they sometimes present only slight injuries consisting of ecchymomata or excoriations (in some cases the skin is almost completely whole).

Sometimes, on the contrary, almost complete skinning has been met with (FRACHE, 1954,12) with vast strips of the teguments of the neck, back, chest and abdomen, including also the complete skin of the penis peeled off like the finger of a glove, or vast strips of the teguments of the limbs, particularly the lower ones, up to the heel. In the latter cases the skinning and dismemberment effects, with large cutaneo-muscular tears and the projection of fragments of the body far away, together with the concomitant phenomena of the bursting of the cranial, thoracic and abdominal cavities, are to be attributed to the explosion, which has acted with the double mechanism of sudden compression and decompression ; to those two major injuring actions there must generally be added a third traumatic mechanism, namely the possible action of metallic fragments derived from the explosion of the plane, fragments which, moved by a considerable kinetic force, act upon bodies either as bruising agents or as cutting edges.

If a fire breaks out after the fall of the aircraft, burns or scalds are often found in the teguments of the parts of the body exposed to the action of the flames or the heat. These skin burns, which generally take place in the final phase of the accident, that is, after impact on the ground, and are therefore post-mortal, usually lack the characteristics of vitality, as is shown by the absence of appreciable reactions at the skin level.

Even in the case when the remains of the plane and the bodies of the victims fall into the sea, skin burns have been met with. In most of the corpses recovered in the sea in the accident of the Comet which crashed on 10 January 1954 south of the island of Elba, FORNARI (1955,11) found - particularly in the areas covered by clothes - post-mortal skin injuries presenting the characteristics of scalds and which might have been caused by contact with overheated liquids, vapours or gases or more probably since the bodies had floated in the sea for about four hours before being recovered, by contact with the surface of the sea water overheated by the kerosene in flames.

Characteristic and worthy of mention is also the "darkening" of pigmentation described by the British authors ARMSTRONG, FRYER, STEWART and WHITTINGHAM (1955,2) in the victims recovered in the sea when a Comet crashed in the gulf of Naples on 8 April 1954 ; this typical pigmentation, met with only in the uncovered areas of the cutaneous surface of the bodies, which had been floating in the sea for about twenty-two hours before being recovered, and had therefore been exposed to the action of the sun for all the daytime hours of a bright spring day, is in all likelihood to be attributed to the so-called "Meirowsky phenomenon", that is, the intensification of normal skin pigmentation which may take place even after death as the result of prolonged exposure to the ultra-violet rays of sunlight.

Still as regards the appearance and characteristics of the external teguments or what remains of them, it should not be recalled that a good many data useful for the identification of the corpses can often be obtained from examination of the scalp and the soft tissues of the face, especially if they are quite well preserved : colour and length of hair, body hair and beard, type of shave, complexion, somatic features of the face, shape of the nose and the auricles of the ear, beauty-spots, scars, finger prints, etc.

INTERPRETATION OF THE VARIOUS TRAUMATOLOGICAL PICTURES. DISCUSSION.

From all that has been said up to now about the skeletal, visceral and cutaneous injuries that are usually found in the victims of air disasters, it is clear that the injuries met with in the skeleton, the internal organs and the external teguments may be multiple, multiform and combined with one another in different ways according to the dynamics of the accident and the phase of the accident in which the single injuries were produced. Nevertheless, experience in the matter of injuries resulting from aircraft crashes enables us to affirm that, generally speaking, the traumatological picture produced by an air disaster can assume - as happens for other events causing injuries - specific characteristics according to the particular ways in which the accident was produced and took place ; and that in this way it is nearly always possible to draw from the traumatological picture data that are useful for the purpose of reconstructing the causes of the disaster, and of value, therefore, also for the purposes of preventing injuries due to air

craft accidents, or at least to reduce their harmful effects as much as possible.

It is not difficult to arrive at these conclusions if a systematic and methodical examination is made and compared with the anatomo- and histopathological findings in victims of the major air disasters that have taken place both in commercial air lines and in the Air Force ; in the latter particular sector of plane accidents, in fact, the traumatological pictures present more constant and uniform characteristics, and it is therefore less difficult to place them both on the nosological and the pathogenetic planes.

Well, the conclusive evaluations at which it seems possible to arrive through comparative analysis of the single plane accidents or disasters which I have been able to observe directly or indirectly in the course of 25 years of personal experience in aviation medicine and aviation legal medicine, can be summed up as follows.

The exact and correct interpretation of the traumatological data collected or described on the victims of air disasters, affords, generally speaking, the possibility of envisaging the ways in which a given aircraft accident has taken place and to reconstruct its various phases, to each of which there generally correspond well-defined injuries.

A preliminary distinction of a general character that is of very great importance in traumatological findings is the subdivision of the injuries met with in victims of plane crashes into two main categories : vital injuries and post-mortal injuries.

This subdivision, which from the diagnostic point of view is based - as is known - on the presence or absence of haemorrhages, haematic infiltrations or suffusions at the edges or at the back of wounds or within the cutaneous or muscular planes affected by the injuries, does not generally present great difficulties in air accidents. Since, in fact, the death of the victims is usually instantaneous, there is in most cases a clear distinction between injuries "intra vitam" and injuries "post-mortem", in the absence of injuries - falling between the two - that have an intermediate aspect such as the ones that take place in the course of the death agony, the characteristics of which are uncertain and difficult to differentiate.

It is obviously unnecessary here to deal more thoroughly with post-mortal injuries. Usually consisting in the effects of contusing traumatisms connected with the violent impact on the ground of bodies that are often already lifeless and in the effects of the subsequent exposure of the bodies to various injuring agents (atmospheric factors, excess thermal energy owing to a fire, etc.), they occur in the terminal or post-terminal phases of the accident, which are the least interesting from the pathogenetic standpoint.

The examination and etiogenetic interpretation of the vital injuries are far more important, on the other hand, for the purposes of reconstructing the ways in which the accident originated and took place. These injuries - according to their differential characteristics - can be attributed, as the case may be, to the effects of precipitation, or of explosive decompression with subsequent precipitation, or of impact on the ground followed by an explosion or not, or of explosion in flight followed by impact, or finally of the terminal fire.

Most of the bone fractures and visceral ruptures are to be attributed - in the absence of characteristic data on any of the other traumatic mechanisms - to the precipitation from a great height of the aircraft, with which the bodies of the victims necessarily form one.

In this case the serious injuries, mainly cephalic and thoraco-abdominal ones, which are generally the immediate cause of the death of the subjects, are all produced more or less at the moment of the impact of the plane, either by the action of a violent decelerative force in the antero-posterior direction, produced during the impact itself, or by a latero-lateral force due to the collapse and crushing of the fuselage. As a result of the violent shock and subsequent bursting of the latter (even in the absence of a real explosion), the bodies of the passengers may be violently hurled outside with a whirling motion ; and, still as a result of this whirling force of great intensity, injuries can also be produced, typically at the roots of the limbs, both upper and lower, consisting of lacerations of the external teguments along the axillary and inguinal folds, which sometimes affect also the musculo-aponeurotic planes and may even tear off the limb completely ; bodies may furthermore be partly stripped in this way and are sometimes injured by cuts caused by metallic fragments of the broken structures of the plane, acting as cutting edges.

Explosive decompression due to the sudden opening of a hole in the walls of the pressurized cabin, with the subsequent precipitation of the bodies, involves "intra vitam" injuries characteristic of decompression (haemorrhages and parenchymal lacerations) and injuries, also vital ones, due to contusing violence owing to the intervention of other factors causing injury, such as sudden deceleration in flight at the moment of the decompressive explosion, the shaking of the passengers almost like the clapper of a bell and the hurling of their bodies against the internal walls of the cabin (limited skeletal

fractures, visceral ruptures, contusions and injuries to teguments) ; as well as "post-mortem" injuries caused by the impact of the lifeless bodies falling upon the ground or the sea from a great height (multiple and comminuted skeletal fractures mainly in the limbs, extensive cutaneous lacerations) ; there is, however, no peeling off of the skin and complete disintegration, since the impact of the body does not accompany its explosion.

As regards in particular these deaths due to sudden and violent depressurization, it should be stated that for decompression to have fatal effects it must be of extreme violence and scope, that is, it must take place with very high gradient and speed of decompression. In these cases of death due to decompression, in which pulmonary and cardiac injuries predominate, an often very important and determinant role is played also by fulminating anoxia and by aeroembolism, to which subjects decompressed explosively at very high altitudes are subjected.

At this point it should also be added that it is not always possible to find out for certain whether decompression is the cause of death under such circumstances or not, since the injuries, particularly the pulmonary ones, typical of explosive decompression are obviously nearly always associated with, and superimposed upon, many other of the above-mentioned pre- and post-mortal injuries of various type and origin, due to numerous other traumatic and non-traumatic factors which certainly intervene in the dynamics of this type of accident, such as :

a) the violent displacement and the consequent violent impact of the bodies of the passengers against the structures of the plane at the moment of the sudden deceleration in flight and as a result of the expulsive force of the air going out of the hole in the pressurized cabin during the sudden depressurization ;
b) the effects of free fall from a high altitude ;
c) the impact of bodies upon the land/water surface, an impact which, as has been seen, can also bring about injuries to various internal organs, and especially the lungs, very similar to the ones typically caused by explosive decompression, such as parenchymal and subpleural haemorrhages along the ribs, emphysema with alveolar lacerations, atelectasis etc. ; and finally
d) the exposure of the bodies to the action of other exogenous factors during floating on the sea or lying on the ground before being found.

The impact of the body on the ground, after passively leaving the cabin as it precipitates and falling freely in space, causes - as a consequence of the violent shock - a fragmentation of the body in segments which are, however, still united, though the musculo-tendinous parts are dissociated and the skeletal parts crumbled, but with a relative respect of articulations. Impact on the surface of the water, which, as is known, in precipitation from great heights represents an extremely resistant substratum, produces similar effects.

If impact upon the land/water surface is followed by an explosion, for example of fuel vapours, the fragmentation of the body becomes even more minute, and may reach the point of more or less complete disintegration according to how near it is to the source of the explosion ; it is also accompanied by the emptying of the coelomic cavities, which impact upon the ground, however violent, cannot cause by itself.

In particular the explosion, taking place with the double mechanism of sudden compression and decompression, is the cause of the bursting of the cranial, thoracic and abdominal cavities and of the skinning and dismembering effects with the hurling of fragments of the body far away, as well as the lamination of the cutaneous coverings which are completely separated from the underlying muscular planes, and the fraying of the tendons at the fractured and amputated extremities.

Other skin injuries that can be met with in these cases are the ones caused (as has been seen) by the action of the metallic fragments derived from the explosion of the plane, which, propelled by great kinetic force, act on the bodies both as blunt and as cutting instruments ; in these cases burn phenomena can often be noted also, owing to a fire breaking out immediately after the fall of the plane as a result of the explosion.

A characteristic finding is, finally, the absence of signs of vital reaction particularly at the edges of the wounds of the disintegrated bodies. This can easily be explained by the instantaneous destruction of the cardiocirculatory system which takes place in circumstances of the kind ; these signs of vital reaction are present, on the contrary, at the edges of injuries in the less seriously damaged bodies, in which the destruction of the cardiocirculatory system has therefore been less rapid.

Another eventuality to be taken into consideration is that of an explosion followed by impact. In this case, in addition to the typical pulmonary air blast injuries, metallic splinters due to the fragmentation of the shell of the bomb and to metallic parts of the fuselage damaged by the explosion, are constantly found in the bodies of the victims ; there are furthermore skin burns and the singeing of piliferous formations produced by

the blaze of the explosion. Only rarely, finally, does the explosion give rise to disintegration, which in any case is always strictly limited to the centre of the explosion ; more often the bodies show amputations of large fragments of limbs, especially at their roots, of parts of the body etc. but, though greatly mutilated, they have still a considerable part of viscera in the coelomic cavities : this can be explained by the fact that the explosion, being the primary event, was not preceded by a fragmentation of the bodies produced otherwise.

Finally, a last possibility should not be forgotten : that is, that in an air accident that is not too serious, and would otherwise have been compatible with survival (for example : violent landing with simultaneous or subsequent outbreak of fire on board), the death of the occupants is directly caused not by traumatic injuries due to impact, but by the serious and extensive burns that may be caused by the flames or blaze of the fire, or even exclusively by the inhalation of smoke or toxic gases (CO, CO_2) and/or even by the mechanical obstruction of the trachea and the bronchi and bronchioles by carbon material produced in the combustion of fuel, water-soluble oils and internal material of the cabin.

Particularly important in such circumstances, for the purposes of the pathogenetic interpretation of the traumatological picture and therefore in the reconstruction of the various phases of the accident, is not only the anatomo-pathological finding of serious and extensive vital burns but above all the toxicological findings, for example, considerable quantities of CO in the blood or in parenchymas rich in blood, the presence of which indicates - in case of fire - that the subject was alive before it broke out ; in the same way the presence of smoky materials in the airways and in the lungs bears witness to a state of vitality at the time of the fire.

Of course in every type of accident useful indications can be obtained not only from finding specific types of injuries, but also from the absence of anatomo-pathological effects connected with particular mechanisms of injury : for example, the lack of air blast phenomena in the thoracic and abdominal cavities, accompanied by vast skinnings and minute dismemberments and burns on some fragments of the body (injuries typically produced by the explosion of petrol vapours), makes it possible to exclude in this case the explosion and burning of the plane in flight or at the moment of impact.

The same applies to the finding that the typical injuries due to explosive decompression are absent, which makes it possible to exclude the possibility that a similar event took place in flight and contributed to the genesis of the accident and to the production of its harmful effects ; and so on.

CONCLUSIONS.

The knowledge and exact interpretation of all the possible correlations between body injuries and traumatizing causes is of great interest not only for the purpose of identifying the causes of the accident, but also to offer technicians useful indications about the causes and mechanisms that produce the body injuries and above all about the factors that determine and condition the greater or lesser seriousness of the injuries and whether or not they are fatal. In this way aviation technicians can design and carry out all the opportune and necessary devices to eliminate agents causing injuries or at least to prevent or reduce their effects as much as possible.

In order that aviation engineers may be able, with adequate designing of all the elements that make up the aircraft and particularly the cockpits, to prevent or reduce to the minimum the serious or even fatal injuries that often take place in flying accidents that are not equally serious and such, in any case, as to be compatible with survival, they must be supplied with detailed, precise and complete data on the nature, dimensions, locality and seriousness of these injuries and on the biodynamic mechanisms with which they were produced in the individual accidents.

What has been previously illustrated and discussed has confirmed to us, in fact, that from a careful and methodical study of air accident traumatology, useful indications can be drawn for the reconstruction of the causes of air accidents and the ways in which they took place ; there is no doubt, therefore, that as a result of this analytical and systematic study it will be possible to make a further important contribution to the solution of many problems regarding the prevention of fatalities in aviation accidents.

The experience acquired so far in this preventive field of aviation medicine has already made it possible, for example, to study and carry out - in the stage of the designing and construction of aircraft and of their flight equipment - many providential devices that bring about a diminution of the frequency and seriousness of injuries due to air accidents, such as : the use of adequate safety belts and reliable containing and restraining systems, which also operate automatically ; the adoption of measures to prevent or reduce the danger of fire and to protect the occupants from its direct effects and from the inhalation of the toxic gases, smoke and smoky material to which the fire gives rise;

the provision of sufficient and suitable emergency exits and the adoption of reliable systems of rapid or even automatic evacuation ; the elimination of mobile objects inside the plane, which become projectiles during impact ; the adoption of devices in the construction of the aircraft which may represent a protection against body injuries, such as, for example, the elimination of sharp and protrunding parts, the padding of metallic structures, the use of material that yields and does not splinter in the manufacture of some structural parts of the plane, etc.

These and the further results, which have been and will be obtained through study and analysis of injuries due to aircraft accidents, have made, and will continue to make also in the future, an important contribution to the prevention of air accidents and their harmful effects, and to increasingly complete and efficient flight safety.

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LEGAL ASPECTS OF FLYING ACCIDENTS INVESTIGATION

DISASTER VICTIMS IDENTIFICATION

by

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SUMMARY

The legal regulations of every civil Country lay down that no corpse can be buried before being identified.

Personal identification, not at all easy in normal conditions, becomes very difficult in aviation disasters because of the disfiguration of bodies, caused by serious injuries or burns, and because of the high number of victims.

In this paper biological and non-biological systems for identification will be dealt with.

INTRODUCTION

After death, human beings stop being "legal persons", losing consequently all the benefits connected with the live state, while post-mortem effects arise at the same time.

Besides legal reasons, also sentiments of piety require identification of the dead before burial.

Because of the high number of victims, and above all, because they are frequently disfigured by injuries, burns, or mutilations, passenger identification in aircraft disasters is always a very complex operation; in order to carry it out biological or non-biological methods can be used, the former based on the examination of the corpse, the latter on that of clothes and personal effects; both will be dealt with in this paper. In any case it should be kept in mind that to reach the goal it is not necessary to use all the methods, but only the idispensable ones; the others can be omitted when identification is reached.

FOREWERD

Before starting the identification operation, when there are many corpses at the place of the crash, each of them must be marked with a reference number, written on a tag in indelible ink; the tag must be attached to the body on neck, wrist or leg and so on, and not to the stretcher or blanket in which it may be wrapped.

Victims must not be removed from their first position until inquiries have been completed on the spot; corpses and wreckage must be photographed and recorded in their reciprocal places. After these first operations, corpses can be picked up, put into provisional coffins and forwarded to a Forensic Medicine Institute.

IDENTIFICATION SYSTEMS

A) - NON-BIOLOGICAL METHODS

Personal identification by non-biological methods are used more by the police than by medical investigators; the methods belong to the groups:

1 - direct identification;
2 - identification by exclusion;
3 - identification by examination of clothes and personal effects;

1 - Direct identification

Direct identification can be obtained in two different ways:

a) - by confrontation of victims with their own documents;
b) - by visual recognition by persons who previously knew them.

These methods may fail for one of the following reasons:

a) - documents are missing;
b) - the victims are foreigners and there is nobody on the spot who can recognize them.

2 - Identification by exclution

This is an indirect method (and for this reason not absolutely sure), which can be used in addition to other tests.
The method is applicable when the names of all passengers boarded are known and when all have been identified but one; the latter's name can be drawn from the list of passengers.

The weak side of this method is due to the fact that the names on the passenger list do not always correspond to the passengers really boarded.

3 - Identification by examination of clothes and personal effects

For identification, clothes and personal effects must be described very objectively,

avoiding all expressions based on personal conviction (so instead of"gold ring", the expres sion "yellow metal ring" should be used, and so on).

a) - Clothes examination

Information will be given about outer and inner garments regarding:

- type;
- colour;
- shape and size;
- further information (manufacture labels, tailor tags, laundry marks, etc.)

The same will be done for shoes, gloves, ties, etc.

b) - Personal effects

A careful description must be made of the effects worn by victims or contained in pockets or bags, such as:

- spettacles (type, sunglasses, contact lenses, etc.);
- watches and jewellery, keys;
- documents;
- money (type of coins, banknotes, cheques, bank books,);
- photographs, badges, cameras, recorders;
- papers and magazines;
- luggage and other items.

The above data give information about nationality, family, profession, place of living and working.

The objects collected must be put into envelopes and marked with the identification number allotted to the corpse.

B) - BIOLOGICAL METHODS

Identification by biolcgical methods utilizes medical tecniques regarding the following four groups:

1) - definition of race;
2) - determination of sex;
3) - estimation of age;
4) - determination of individual characteristics.

Before beginning any medico-legal operation, cadavers should be photographed and X-rayed.

1) - Definition of race

In order to define race, the elements that can be utilized are the following:

- physiognomy;
- anthropometric sizes;
- colour of the skin;
- characteristics of the hair.

The analysis of the above elements makes it possible to establish the race of a man. When fire has destroyed external tissues, definition of race is based only on anthropometric sizes.

2) - Determination of sex

In normal conditions (apart from cases of doubtful sex), the determination of the sex of a person can be easily achieved by examination of genitals; difficulties arise when they are missing, as in cases of carbonization, or mutilation.

According to cadaver conditions, sex ascertainment can be made as follows:

a) - Genitals examination

This is an easy way of evaluation but feasible only when genitals are present and normal.

b) - Analysis of secondary sexual caracters

There are differences between the two sexes to be taken in consideration ; they are:

- beard (missing in woman);
- breasts (well developed in woman);
- muscles (muscles in man are bigger than in woman);
- anthropometric data (different in the two sexes).

As regards this last item, it is known that there are some differences between the two se xes, as reported below:

- Shoulders/ pelvis breadths (obtainable by measuring bideltoid and suprailiac spine brea dts): in man bideltoid breadth is wider than suprailiac one; the contrary in woman.
- Pelvis (measured between left and right suprailiac spines): in females it is larger than in males.
- Thigh/leg lengths (obtainable by measuring the distance between troacanter and medial point of knee for the thigh, and the distance between this latter point and tibial malle olus for the leg): in woman, the thigh is generally longer than the leg; the contrary in man.

3) - Estimation of age

Biological age does not always correspond to the chronological one; when the age is drawn from biological characteristics, it must be defined as "apparent age".

The elements utilizable for defining age can be:
- general external aspect (especially as regards the face);
- hair colour (hair becomes grey over 40);
- skin characteristics (the skin of elderly people loses elasticity and gets brown spots);
- muscles (in elderly people they become ipotonic and ipotrophic);
- dental characteristics (in teen-agers 3rd molar is not yet present; in most elderly people teeth are often missing);
- joints (in elderly people there are frequent arthroses);
- spinal column (in elderly people are frequent cervical and lumbar arthroses, marginal osteophitosis and extradiscal synostosis; vertebral disks undergo a fibrous involution, nucleous pulposus tends to lose its gelatinous appearance, its separation from anulus fibrosus becomes vague);
- skeletal growth (under 20 skeletal growth is not yet complete; in younger men ossification centres are still present);
- calcifications (in elderly people there can be presence of calcium on artery walls, with osteoporosis).

4) - Determination of individual characteristics

Individual characteristics are specific properties by means of which it is possible to distinguish one person among many others of the same race, sex and age.
The elements utilizable are:
a) - height and bodily weight;
b) - physiognomic characteristics;
c) - anthropometric data;
d) - peculiarities;
e) - elements furnished by X- ray examination;
f) - dental characteristics;
g) - biological prints;
h) - blood groups.

a) - Height and bodily weight

Height and bodily weight give information about individual built.
On the cadaver, height can be obtained by measuring, by anthropometer the body lying in supine position; the height correspond to distance between cervical vertex and heel.
When head or lower extremities are missing, the height can be approximately obtained by measuring upper limbs span, or from long bones measurement, applying "Manouvrier tables" or "Rollet coefficients".

b) - Physiognomic characteristics

Physiognomic characteristics are certainly the most important elements for identification; obtained from face examination, they regard:
- general appearance (pretty, ugly, indifferent);
- skull shape (brachicephalus, dolicocephalus, mesocephalus);
- face shape (oval, circular, with marked or smooth lines);
- race characteristics;
- skin characteristics;
- hair: - type (smooth, wavy, curly);
  - colour (natural or dyed);
  - length (whether recently cut);
  - baldness (total partial);
- beard (colour, shape, length);
- moustache (colour, shape, and length);
- mouth and lips;
- nose (type, shape and size);
- ears (shapeand size, type of lobes and if pierced in females);
- eyes (shape, size, colour of the pupils);
- other peculiarities of the face.

Face should be photographed.

c) - Anthropometric data

There is quite a number of anthropometric elements that can be utilized for identification, such as:
1 - Head measurements
- circumference of skull (taken by passing a tape around head, just above lower brow ridgesand over occiput);
- bitragion-coronal arc (measured vertically with a tape, from tragions of two ears);
- bitragion diameter (measured horizontally with a caliper between the two tragions);
- Maximum head diagonal from chin (closed jaw, it is obtained by measuring distance between chin and vertex);
- neck circumference (measured with a tape passing around neck, immediately below larynx).

2 - Trunk measurements:
- bideltoid breadth (measured between edges of anthropometer in light contact with the two deltoid muscles);
- Vertex - buttock distance (measured between vertex and buttock);
- chest circumference (measured by tape placed horizontally around chest at nipples level);
- waist circumference (measured with a tape passing horizontally around waist, lower edge of the tape being aligned with waist marks).

3 - Extremities measurements:
- upper extremities length (distance between acromion and tip of 3rd finger);
- span (breadth of two arms, measured between tips of 3rd finger, with arms stretched laterally and horizontally);
- lower extremities length (distance between superior iliac spine and heel);
- if necessary, other sections can be measured in addition.

d) - Peculiarities
- build (normal, obese, thin);
- skin characteristics:
  - colour;
  - moles;
  - scars (location, shape and size, surgical caused by burns, injuries, hardness, adherence, vaccination marks);
  - tattoos;
  - abnormalities (tumours, changes in colour, distrophies);
- nails (length, deformities, nail polish);
- birthmarks;
- malformations;
- circumcision;
- abnormalities (previous amputations, consequence of illnesses, traumatism or surgical operations, congenital malformation);

e) - Elements obtainable by X-ray examination

Radiological examination on the cadaver can give useful information for identification its main applications regard skeletal examination, very useful especially when softs tissues are destroyed by flames; by X-rays examination, it is possible to drow the following elements:
- length of extremities bones (useful to determine height);
- structure of the bones (bearing in mind that in elderly people it is easy to find osteoporosis or other regression changes, while in teen-agers ossification nuclei may still be present;
- congenital malformation;
- post-traumatic modifications (dislocations, callus and other signs of fracture consolidation);
- pathological osteo-articular changes (arthroses are frequent in elderly people);
- in addition to skeletal patterns, other X-ray elements can be utilized for identification (calcolus, calcifications, etc.).

f) - Dental characteristics

Apart from cases of decapitation, dental examination is useful for identification even when soft tissues are largely burned.

In order to save time (it must be kept in mind that in aircraft disasters the number of casualties is very high) and to obtain more information about personal identity in addition to objective dental examination, it is advisable to make a radiological one too, not only of dental apparatus but also for whole mouth, in order to obtain elements from bones of oral cavity.

By radiological examination it is possible to get information about pathological elements, prostheses, congenital characteristics, (teeth not yet emerged) type and size of teeth, jaws and bony palate. Compared to visual examination, it gives information even when traditional odontogram can say nothing (all teeth present and healthy or missing);
In synthesis, the following data can be obtained:
- number of teeth missing;
- teeth characteristics (small, large, protruding, widely spaced, position, uneven, not emerged, inside and outside colour, artificial elements, malformations, pathological);
- prostheses, orthodonties;
- pathological characteristics of soft and bony parts of oral cavity (tumours, illnesses of gums etc.).

For quickness in execution and sureness in information, it would be useful to introduce a routinary radiological examination of mouth for air passengers, renewable every 5 years; the plates could be attached to the passport or air ticket; so that in the case of

an air accident, they could be compared with the result of the examination made after the accident.

g) - Biological prints

Biological prints are negative images of bodily surfaces left on printable materials.

Below are the numbers corresponding to different finger prints:
(1=thumb, 2=index finger, 3=third finger; 4=ring finger, 5=little finger); in addition, footprints and even lip prints can be obtained.

h) - Blood groups

The determination of the blood group is used by Forensic Medicine for exclusion diagnoses; in other words when it is known that somebody belongs to group "A" and the blood of the victim is "B" there is no doubt that the former is not the latter. On the contrary, no sureness there is when the groups are the same.

Besides ABO groups, other antigens belonging to red cells (such as MNSs, P, Kell, Duffy, Lutheran, Lewis, Sutter, etc.), white cells and serum can be tested.

CONCLUSIONS

The above mentioned methods for personal identification can help aero-medical investigators to identify casualties of aviation disasters. As was said, it is not necessary (and not always possible) to use all methods described, but only the sure ones.

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DISCUSSION

MACLAREN: Do you not believe that routine dental radiological examination of air passengers is logistically and economically impractical and, from the viewpoint of passengers and operators, totally unacceptable?

PAOLUCCI: I don't, because only a short length of time is needed to obtain a radiogram of the mouth, and it could be performed prior to check in at the airport. Of course, it is necessary to have a small radiologic apparatus and one or two technicians available to operate it. Once obtained, the radiogram should not need be renewed but every 5 years.

CHRISTIE: Would you make it a requirement for passengers to carry oral dental x-ray films before boarding an aircraft?

PAOLUCCI: Yes, I would.

CHRISTIE: Would you recommend that these x-ray films be contained in fireproof material?

PAOLUCCI: Yes, if they are to be attached to the passport. This would not be necessary if they were filed and stored in a central office.

PROCEDURES FOR IDENTIFICATION OF MASS DISASTER VICTIMS*

by

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SUMMARY

The problems of identification of mass disaster victims need not be insurmountable if approached in a logical, meticulous, stepwise manner. The identification process is basically the collection of identifying information about the missing persons, observation of identifying features of the victims, and comparison of the two groups of information. Certain techniques, such as comparison of fingerprint and dental records, are more reliable and are believed to provide positive identification. On the other end of the reliability scale are such characteristics as height, weight, skin color, and hair color, which may be subjective, may be difficult to measure, and are subject to change but which in combination may provide reliable and, in some cases, the only identification. The "odd man out" method is a practical technique for screening identification.

Careful application of these techniques and observations of the pitfalls will enable even the inexperienced investigator to collect valuable information to simplify and shorten the identification process. It is only by practice that the inexperienced become experienced.

INTRODUCTION

Accurate identification of persons who have been fatally injured in an aircraft accident or other mass disaster is an essential element of an adequate investigation, and one obvious reason for identification is to allow families to recover the correct body for burial, as is customary in our culture (1). In past investigations, identification has often been incorrectly or inadequately attempted by persons with little experience or knowledge of problems of identification. In many of those cases, identification was made solely on the basis of visual inspection, by "dog tags," or by articles of clothing (1). Families have simply been allowed to claim portions of bodies even when no identifying characteristics were present, and in mass disasters involving victims whose religious beliefs require proper burial or prompt burial, families have been quick to claim any body. Conversely, the emotions following death of a family member have on occasion resulted in denial reactions, and families have refused to accept unequivocally positive identification of their relative. While in most cases even visual inspection is more than adequate, the investigator must be aware of possible subsequent litigation or insurance claims that may hinge upon documentation that the victim was, in fact, as purported.

ORGANIZATION

Time spent on pre-disaster planning will be more than recovered from the resulting expediting of the identification process following occurrence of a disaster. Likewise, structuring of the individual efforts and implementation of the previously designed plan can effectively be the most important step taken when a disaster does occur (2).

A central headquarters must be established to control and monitor progress in the investigation and maintain necessary liaison. This headquarters must be easily accessible to transportation and communications. Accommodations for eating and sleeping may be necessary, as well as suitable isolation for families, news media, and other persons who have a legitimate interest in the investigation but whose presence may distract investigators, resulting in errors of identification.

Subordinate commands may be located at the disaster site, at the treatment facility, and at the mortuary or identification facility. Strict security is desirable at these subordinate commands as well, to enable efficient operation with a minimum of interruptions.

Establishment of an effective communications system should have high priority. Information for correlation with identifying characteristics must be sought from outside sources.

The conditions under which the investigators must work will often influence the speed with which the problems can be resolved. Especially in adverse climatic conditions, work schedules should be established. Errors made as a result of fatigue, hypoglycemia, or cold can delay the investigation far more than any possible time-saving from extended hours of work under adverse conditions.

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*The opinions or assertions contained herein are the private views of the author and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

DETERMINATION OF WHO IS MISSING

The ability to answer accurately the question, "Who is missing?", as early in the investigation as possible will determine how long the investigation will take, what methods will have to be used, and the types of additional assistance that may be required.

The easiest situation to contend with is a manifested affinity group. An example is military members who are aboard a military aircraft that crashes. In this case, a manifest, or list, of persons who boarded the aircraft will almost certainly be available. Since the crew members are probably from a single organization, information for identification should be readily available from that organization. In addition, it is improbable that persons who were not on the manifest were aboard the aircraft. A problem arises, however, when there is a last-minute crew change without a change in the manifest or when passengers board the aircraft at the last moment and are not included on the manifest.

The most difficult situation arises in the case of a disaster that occurs without a pre-existing list of persons suspected of being missing. For example, if migrant farm workers have entered a country illegally and are involved in a fatal motor-vehicle accident, an extraordinary degree of international cooperation may be necessary to develop a list of the missing persons. Otherwise, it might be months before families realize that their relative, believed to be hard at work on a farm, is actually missing. Hardly a large medical examiner's or coroner's office has not had a body that has remained unidentified for months until a "missing persons" report is filed by a relative.

Somewhere in between these types of situations lies the problem of disasters at airport, bus, or train terminals and sports stadiums (3). There may be little to do but wait for reports of missing persons.

Additional problems arise when people travel under assumed names. Immediately, questions of illegal activity and foul play arise. More innocent circumstances are usually the case, however. An example is that caused when a large corporation makes travel reservations for an employee but at the last minute sends a different employee instead; another is that of an executive who sneaks off with his secretary for a little holiday fun. Of course, simple errors such as misspelled names on a manifest can also pose serious problems in discovering the identity of the missing persons.

DETERMINATION OF WHETHER ALL OF THE BODIES HAVE BEEN RECOVERED

If it is certain that all of the bodies have been recovered, it may be possible to identify some of the victims by a process of elimination. If it is reasonably certain that the "missing persons" list does correspond to the identities of the recovered bodies, the problems of identification are greatly simplified. In this situation, the degree of presumptive identification necessary to approximate a positive identification need not be as great. Identification cannot be presumed, however, unless <u>all</u> of the bodies have been recovered <u>and</u> the list of missing persons is complete.

When bodies are fragmented, special care must be taken in collecting, tagging, and identifying each fragment (4). It is not difficult to visualize the problems that arise when eight persons are missing and body fragments including 17 feet are found. Obviously, the identity of the ninth missing person must be sought, and the entire process of identification will be much more difficult and time consuming than if the identity of the ninth missing person is known.

Even small fragments of tissue may aid the identification process, especially if the fragment consists of teeth or printable skin from the fingers (5). Special efforts must be made to search the scene carefully, inch by inch, to insure that nothing has been overlooked.

In some instances, such as in disasters at sea, the reality of the situation may be that it will be impossible to recover all of the bodies. Three issues then arise: First, a determination must be made as to when any further search efforts will be futile. Second, the possibility may exist that there may have been more victims than persons reported missing. Third, the possibility of foul play may have to be resolved by other aspects of the investigation.

SELECTION OF IDENTIFICATION TECHNIQUES

From a practical standpoint, there are three general rules to follow: First, do the best you can with what is available. Second, do the easiest things first. Finally, don't release a body until positive identification has been made.

Positive identification of a person is made when a sufficient number of objective features are identified that belong to that person and only to that person. All of the methods of identification that are currently used involve comparison of observed characteristics of the bodies with known or reported characteristics of persons missing or presumed to be dead. There is no doubt that it is possible, theoretically at least, for two people to have certain characteristics that are similar enough to be, for all practical purposes, identical. For this reason, a certain degree of probability must be assigned for each method of identification. The greater the number of identical characteristics found, the more certain is the probability that the identification is positive. For example, the certainty of identification is much greater if 25 fingerprint or dental characteristics are found than if the only comparable features are blood group substance A.

How many presumptive correlations are necessary to approximate a positive identification? No set number can be stated unequivocally. Correlation of three characteristics such as height, weight, and hair color will usually not have as much weight as correlation of evidences of operations and other

scars, congenital defects, and dental restorations. On the other hand, if only one of the missing persons weighed over 150 pounds, and if he happens to weigh 250 pounds, this might be a very significant identifying characteristic indeed.

A high degree of negative correlation may also be of great value in limiting the number of persons under consideration. For example, if it is determined that 20% of the victims have blood group substance A, the missing persons known to have blood groups AB, B, or O are not likely to provide a match.

In some cases, methods that could not be used to establish identification when applied to a large number of bodies may be used as good evidence of identification by the method of "odd man out." The odd-man-out theory was proposed by Mason for evaluation of distinctive injury patterns in reconstruction of the cause and sequence of events in an aircraft accident (6), but it is equally applicable as a technique for preliminary identification of fatalities. Initial screening examination of the bodies will almost always reveal that certain of the bodies have characteristics on which the investigator feels comparison data will be easy to find. Pregnancy, the presence of a glass eye, or an artificial limb are typical of kinds of identifying data that are not usually sought in identification questionnaires and yet can be extremely valuable information when found. The presence of any one body with features different from all other bodies found in the wreckage sets the odd-man-out process in motion.

The "odd man out" method does not require that the characteristics be totally unique to simplify the process of identification. If all of the passengers and crew were male except for one female flight attendant, the only female body found would be presumptively identified as the female flight attendant. Unfortunately, there may be times when an identifying characteristic is found that almost certainly must be unique, that only one person in the whole world could possibly have, and yet on which no antemortem record of missing persons can be found to substantiate the finding.

In another form of application of the odd-man-out theory, consider the situation in which 10 persons are found in the wreckage. If half of the persons were blood group A and the other five were blood group B, the determination of blood group would not establish even presumptive identification of any of the fatalities. If eight of the bodies had already been positively identified by means of fingerprints, however, and if one of the two remaining bodies was blood group A and the other was blood group B, then reliable presumptive identification would be established.

There are certain pitfalls to be avoided in application of the "odd man out" method. There is a temptation to think of the odd man as being positively identified. This is not a valid assumption. The greater the certainty that the 10 victims found are the 10 persons reported missing, the greater the probability that the odd man will be identified. Also, great care must be exercised to insure that the odd man is not eliminated too early in the investigation on the basis of a characteristic that was improperly described or was, in fact, not unique. Again, the investigators should be cautioned to avoid the temptation to release bodies on the basis of inadequate identification.

TOOLS OF IDENTIFICATION

Dentition. With the exception of visual recognition, dental identification is probably the most widely used method of identification of unknown remains (7). More people have dental records than have fingerprint records, and the techniques of dental examination are almost, if not equally, as accurate as fingerprint identification. Even when the actual dental record cannot be obtained, it is possible to obtain the necessary information by telephone from the dentist of the suspected missing person.

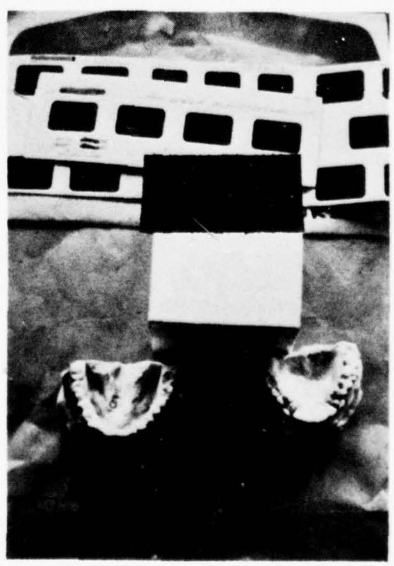

Figure 1. Dental charts, x-ray films, casts, and other materials that may aid identification. (AFIP Neg. 76-925-7).

There are certain problems inherent in dental identification. It is essential that there be at least a general idea as to who the victim is, since you must ask for his records, and there is no central repository of coded dental records, as there is for fingerprints.

Another major problem is that the dental chart does not necessarily show the actual dental characteristics but the examining dentist's interpretation of his findings from the examination. In many cases, this information is verbally transmitted to a technician, who records it on the dental chart. There are many possible sources for errors in this system, and it is not unusual to find "left" recorded when "right" was intended or "buccal" recorded when the actual location was "lingual." This problem of erroneous information has been somewhat alleviated by introduction of other dental records than just the dental chart (5, 8). Dental x-ray films as well as plaster casts may be available (Fig. 1). Comparison of the root structure of the teeth in antemortem and postmortem x-ray films may establish identification even if no restorative dental work has been performed.

A fourth problem area is encountered when a victim has had dental work performed subsequent to the last known dental record. For example, if person B is believed to have 32 teeth and no restorations, then a victim whose third molars are absent would not seem to be a likely possible match; but it could be that the absent teeth had been extracted subsequent to the date of the record available for comparison. Great care must be taken that possible matches are not eliminated by errors such as this, and comparison of x-ray films is usually helpful in avoiding problems of this type. Again, as with fingerprint records, it may take a great deal of time to obtain these dental records, but time can be saved by taking the x-ray films and doing the dental charting of the victim while the investigator is awaiting the antemortem roentgenograms and charts.

If necessary, the teeth can be removed en bloc and retained for later comparison (1). Using a bone saw, the portion of the maxilla and mandible containing the teeth can be easily removed without disturbing the location of the teeth. In disasters involving massive forces and tissue destruction, the maxilla is frequently loosened sufficiently that the entire maxilla, with the upper teeth, can be removed with only a scalpel.

The person's name or other identifying information is often inscribed on artificial dentures (9). In many other cases a person's dentist will be able to recognize dental work that he has personally performed, or he may recognize other characteristics of the person's mouth.

Fingerprints. Fingerprint identification has been demonstrated to be one of the most accurate and reliable methods for identification of unknown remains. Experienced investigators can examine fingerprints obtained from disaster victims and, using various coding methods, search the massive files that are kept at organizations such as the Federal Bureau of Investigation in the United States (10).

Fingerprint identification is not always the panacea that it at first would seem to be, however. The use of fingerprints as a means of identification is dependent upon the availability of previous known fingerprints for comparison. In many countries no fingerprint records are kept. In other countries, these records are not available on anyone other than convicted criminals. Even in the United States, where a large file of fingerprint records is maintained by the FBI, probably less than 25% of the population has been fingerprinted.

Nevertheless, fingerprints remain one of the most reliable and accurate means of obtaining positive identification. Even when no fingerprint records are available, it may still be possible to make identification by means of fingerprints, as it is often possible to develop latent fingerprints from the missing person's home, office, or vehicle. Drinking glasses and door knobs are objects from which good latent prints may be found. Certainly this is not a technique for the novice, but knowledge of the technique may greatly shorten the process of identification. When latent prints must be obtained, more than just fingerprints may be necessary. For example, the prints from the palm of the hand may be present on a drinking glass, and in this case, prints of the entire hand must be taken for comparison. Comparison of prints found on a check the missing person wrote may require that prints be obtained from the side of the hand as well as the fingers and palm.

Assistance of local law-enforcement agencies should be enlisted in obtaining fingerprints, since personnel of these organizations are generally more experienced in the techniques of obtaining prints. When assistance is not available, the investigator can collect satisfactory prints for later comparison with prints on the records.

Whatever surface (e.g., fingers, palms, feet of the victim) is to be printed should be clean and dry. Almost any ink may be used. The ink should be applied to the surface to be printed from an ink pad or roller to insure even distribution without excess ink. The surface should then be applied smoothly and firmly to a clean paper surface. It is not necessary that special fingerprint forms be used; almost any paper that will retain the sharp definition of the prints is satisfactory. The individual prints must be labeled as to their source, and each separate finger must be clearly identified.

The next task is to find known fingerprints for comparison. This is the step that actually determines how useful the fingerprint method of identification will be in any individual case. If the personal effects found on the body include an identification card that has fingerprints, the process may be very simple and rapid. If the possibilities as to the identity of the victim are limited, as when the aircraft had a complete passenger manifest or when presumptive identification has been made using another identification method, and if previous fingerprint records can be obtained, then positive identification can easily be made. If no fingerprint records are available, however, or if there are no persons reported to be missing, the number of problems of fingerprint identification may be at least time consuming, if not insurmountable.

The fingerprint screening method to be described may be applied to situations in which fingerprint records for comparison are available. In addition, it should be understood that this simple procedure is a screening method and for use in conjunction with other identification techniques. The final comparison for positive identification should be left to experts.

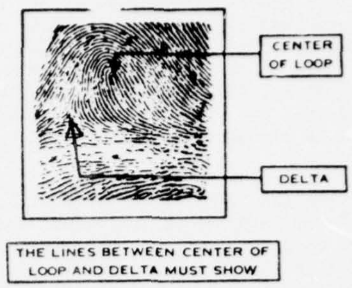

Figure 2. Fingerprint pattern: loop.
(AFIP Neg. 75-15476-19).

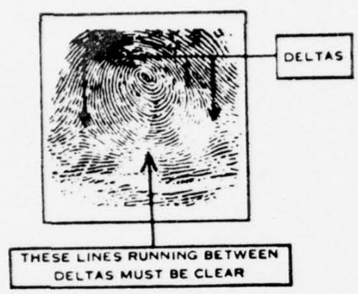

Figure 3. Fingerprint pattern: whorl.
(AFIP Neg. 75-15476-21).

Figure 4. Fingerprint pattern: arch.
(AFIP Neg. 75-15476-20).

Figure 5. Print from left index finger of person A.
(AFIP Neg. 75-15476-6).

Figure 6. Print from left index finger of disaster victim. (AFIP Neg. 75-15476-18).

Figure 7. Print from left index finger of disaster victim. (AFIP Neg. 75-15476-14).

There are three basic patterns of fingerprints: the loop (Fig. 2), the whorl (Fig. 3), and the arch (Fig. 4). These patterns are easily recognizable with minimum training. For example, if a missing person is known to have a whorl pattern on the left index finger, a body that has a loop pattern on the left index finger can almost certainly be eliminated from consideration. Figure 5 illustrates a print from the left index finger of person A. If the fingerprint in Figure 6 was obtained from the left index finger of a disaster victim, the possibility that the victim is person A must be considered since both have loop patterns. In other words, there is a possibility that the victim is person A and this possibility cannot be ruled out on the basis of this single comparison. If the patterns on all 10 fingers are the same on comparison examination, the probability that the victim is person A is even greater. Because the fingerprint in Figure 7 was obtained from the left index finger of a disaster victim, the possibility that he is person A is almost completely eliminated since person A has a loop pattern and the victim has a whorl pattern.

Body Characteristics. Body characteristics other than fingerprints and teeth can be used to assist in screening and identification. The value of an individual characteristic in establishing a positive identification depends upon the uniqueness of the characteristic or combination of characteristics. Some features are easily documented with great accuracy. On the other hand, certain characteristics are affected by subjective observations of the examiner. Observations of color are especially subject to interpretation, and burning or other effects of heat make measurements of height and weight less reliable.

Height, weight, and sex are easily determined, and comparison information is usually available from previous medical records. Problems may be encountered when the body is fragmented.

Estimates of age can be made on the basis of physical appearance, teeth, roentgenograms, and direct observation of bones.

Color, length, texture, and distribution of hair may be helpful, but the interpretation of them tends to be subjective (5). Beards and moustaches are useful, especially if photographs are available for comparison.

Postmortem and thermal effects on skin often make determination of race on the basis of skin color very difficult.

Pierced ears and indications of circumcision should be noted.

The presence of surgical scars, moles, tattoos, or deformities should be noted. Comparison with antemortem photographs may be helpful, depending upon whether the photos have been retouched. Medical photographs are not usually retouched. Postmortem artifactual changes often render skin color an unreliable means of comparison.

Teeth and hands should be examined for clues as to occupation and personal habits, such as callouses in laborers and nicotine stains in smokers. These should be noted.

Medical and dental records are good sources for comparison information. They may not be readily accessible, however, and problems arise when an observer has inadvertently reversed observations of left and right. X-ray films can be helpful, not only for estimates of age but also for locating artificial heart valves, pacemakers, orthopedic plates and pins, and metal surgical sutures. Characteristics such as sex, hair length and color, height, weight, and skin color may be of greatest value in the screening process when combined with other information, and these may provide as positive an identification as will be obtained under the circumstances. It would be impossible to list all of the possible body characteristics that might be observed in a specific disaster victim. Therefore, an awareness of possibilities on the part of the investigator is essential as he pursues his investigation.

Personal Effects. Items of clothing and personal effects provide helpful clues of identity. Jewelry and articles of clothing often are inscribed with names or initials. Wallets contain identification and credit cards, photographs, and other information. Some identification cards contain a photograph and fingerprints. Clothing may be recognized by family members, and labels in clothing may give a clue as to the city of origin (11). Laundry marks can also be used.

Blood Type. Determination of the victim's blood type may aid in the initial screening process in some instances, but this is not usually the case. At best the determination of blood type can be only a screening tool. The antemortem record of blood type may not be readily available. Errors in recording of antemortem blood type may be 20% or higher. The problems of accurate postmortem determination of blood type are even greater. Certain blood-group substances deteriorate rapidly after death, and some bacteria produce blood-group substances that can produce misleading results.

APPLICATION OF TOOLS AND TECHNIQUES

Common sense will enable the investigator to record observed characteristics that are unusual enough that he believes someone should remember and associate it with one of the missing persons. The distribution of sexes, hair color, and body sizes in the group of victims is important. The presence of persons with distinctive dental work, tattoos, surgical scars, or congenital defects should be noted. Personal effects such as distinctive clothing, clothing labels or sizes, photographs, and identification cards can be helpful.

This preliminary examination for distinctive characteristics will suggest the relevant questions that must be asked of the relatives. Family members or other persons can provide helpful information when questioned in a systematic manner. Particularly, they should be asked about the

characteristics observed in the preliminary screening examination. Even if the "missing persons" report includes a questionnaire that lists identifying characteristics, it still may be necessary to request additional information about observed potentially identifiable features.

The questionnaire on identifiable characteristics should include at least:

1. Location of fingerprint or footprint records.
2. a. Location of dental records.

   b. Name and telephone number of dentist.
3. a. Location of medical records and x-ray films.

   b. Operations, hospitalizations, injuries, and identifiable congenital features.

   c. Name and telephone number of personal physician.
4. a. Age, sex, height, weight, and skin color.

   b. Hair color and distribution.
5. Distinctive jewelry and clothing.
6. Clothing sizes and colors.

After reviewing the information given on questionnaires, the investigator should conduct a comprehensive examination of each body, taking special care to search for the identifiable features suggested by the answers on questionnaires. Features that do not correlate can be equally important.

Fingerprints should be made and dental charts prepared. While the investigation continues, other personnel can attempt to locate fingerprint records, dental charts, x-ray films, and other materials for comparison.

A list of characteristics should be prepared for each missing person (example shown in Table 1). Observed positive (+) or negative (-) correlation for each characteristic should be recorded.

Table 1. Evaluation of Observed Characteristics of Victims with Those of Person A

Person	Characteristic and evaluation*					Elimination
	Sex	Height	Weight (lb.)	Evidence of operations	Presence of hair or length	
Person A	M	6' 0"	200	Appendectomy	None (bald)	
Victim 1	M +	5'10"	195	None -	None (bald) +	X
Victim 2	M +	5' 8" -**	200	Appendectomy +	Short -	
Victim 3	M +	6' 1"	185 -***	Appendectomy +	None (bald) +	
Victim 4	F -	5' 2" -	130 -	Appendectomy +	Long -	X
Victim 5	M +	6' 0" +	205	None	Short -	X

*Correlation is shown by plus sign (+), elimination by minus sign (-).
**Was body intact and complete?
***Had victim lost weight recently?

In the example in Table 1, Victim 4 is eliminated on the basis of sex. Victims 1 and 5 are eliminated because they have not had appendectomies. Only Victims 2 and 3 appear to remain for consideration, and Victim 3 seems to provide the best match with Person A, but the recorded characteristics of height and weight are not exact correlations. Several possibilities must be evaluated. Was the body of Victim 2 intact? Are the antemortem and postmortem measurements accurate? Are the other bodies intact and complete? Did Victim 3 lose weight prior to the accident? Also, it is necessary in this case to verify that the Person A did, in fact, have an appendectomy. Additional characteristics should be examined. Of course, if dental records are available, comparison will probably quickly resolve the problem. Screening of other characteristics should be continued.

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DISCUSSION

BALFOUR: No one method of identification is infallible, and even the best method available gives false conclusions occasionally; e.g., a competent dentist may mistake the identity of a tooth if it has shifted into the space where another has been extracted in the past. Is it important to confirm identifications by more than one method whenever possible?

McMEEKIN: Human fallibility is one of the most serious problems confronted by the identification specialist. The example you mentioned is only one of many that illustrate potential sources of misidentification. In addition to those cases in which the identifying characteristics are obscured, there are the problems that arise when the person observing the identifying characteristics, for example, the teeth, is not the same person who is recording these characteristics for comparison. It is difficult to explain how, when the observer announces that a particular characteristic is present on the "right," the recorder marks on the chart that it is present on the "left." The use of multiple identification procedures and observation by more than one examiner significantly decreases the probability of incorrect identification. In cases involving more than one fatality, none of the bodies should be released until all have been identified.

HISTOLOGY IN AIRCRAFT ACCIDENT RECONSTRUCTION

by

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SUMMARY

In many fatal aircraft accidents it will not suffice to perform merely macroscopic examinations of human remains to determine cause and course of events. Frequently, type and sequence of injuries to aircraft accident victims as well as the actual cause of death can only be determined through histology. Even though military pilots are considered a population group having the highest state of health, histological examination of organs of fatally crashed pilots have often revealed diseases, which may have limited their flying fitness. In particular, there are cases of cardiac complications, especially those of coronary sclerosis. Even rare nervous diseases have been uncovered, for instance syringomyelia, and communicable diseases endemic only in certain parts of the globe, e.g. coccidioidomycosis. Discovery of illnesses, which might cause impairment of flying performance of pilots, can indeed help to detect the proper accident causes. The histological examinations of all vital organs of aircraft fatalities may be of paramount importance for the clarification of an aircraft accident.

Research into the causes of fatal aircraft accidents can not be envisaged without utilizing pathological investigations. Foremost, pathologico-anatomical examinations of the accident victims may contribute to the clarification of aircraft accident events. Macroscopic assessment of corpses and the remains thereof will, however, frequently not suffice to elucidate the cause and sequence of an aircraft accident. It is often only through the aid of histology that type and time sequence of injuries incurred by victims as well as the actual cause of death may be established. Moreover, questions relating to time of survival and to vital, agonal or post mortal causation of mechanical, thermal and toxic lesions may be clarified. Occasionally the aviation pathologist will be surprised if microscopic examinations of histological tissue specimens reveal a hitherto unknown pre-existing disease as cause for the flying failure of a fatally injured pilot.

For this purpose it is necessary to secure specimens of all available vital organs during post mortem examinations of fatalities for histological examinations in order to dissect them in the laboratory by applying various techniques and to stain them according to different methods.

The following is intended to demonstrate some of the microscopic findings diagnosed in Division V - Aviation Accident Pathology - of the German Air Force Institute of Aviation Medicine.

The possibility of the victim having survived the accident - and be it only for a few heart beats -, will not seldom be substantiated by the cause of death being pulmonary fat- or tissue embolism, occasionally also cerebral fat embolism. MASON (4) has described the embolic phenomena in detail.

This phenomenon is illustrated in the case involving a 19-year old female flight passenger who had both of her lower legs squeezed off in the abortive emergency landing of an airliner. Upon initial medical care at the site of the accident this lady, who had incurred additional severe injuries, was taken to a hospital where she succumbed after approximately 1 1/2 hours. Microscopic examinations of the pulmonary tissue revealed fulminant fat embolism as cause of death.

From fat embolism of this type a more or less prolonged survival period may be deduced, at least a period of four seconds before death (5). These embolic phenomena should, however, not be confused with the more seldom phanerosis of fat (5) at the pulmonary tissue of incinerated bodies, as illustrated by the example of a 33-year old helicopter pilot, who suffered immediate death caused by multiple traumas involving cardiac rupture and whose body with open thoracic cavity had postmortally been exposed to the effects of fire upon crash.

In addition to fat embolism there are instances of tissue embolism. Especially small liver tissue particles may enter the pulmonary vessels after blunt abdominal trauma, a finding which is surely proof of a certain survival time following the accident. In most cases injuries are of such a severe and multiple nature, that the force of the circulatory system is not sufficient for further transport of the embolus. The emboli then remain situated in vessel areas closely located to the injury, as in the present specimen, which indicates a small mass of liver cells in the lumen of the vena centralis of a hepatic lobulus. The fatally injured pilot had ejected from a crashing jet. The parachute, however, had failed to deploy. The pilot - aged 32 - died of cerebral paralysis after severe skull and brain injuries. Microscopic slides taken of various brain segments revealed severe traumatic lesions to the brain tissue. There are segmental ruptures and strong haemorrhages of the arachnoidea. The ependyma of the lateral cerebral ventricle shows multiple ruptures with blood extravasation below as well as on top of the ependyma. There are also numerous, circumscribed haemorrhages around cerebral vessels with ruptures of the vessel walls. The texture of the brain

tissue is generally dispersed with dilatation of the VIRCHOW-ROBIN-spaces.

Even though military pilots are considered to be a population having the highest state of health since they are regularly under strict medical supervision, histological examinations of organs of fatally crashed pilots have nevertheless often revealed diseases, which may have impaired the flying fitness of these persons and which have been the actual accident cause in some cases. The spectrum of such diseases comprises all possibilities.
Whereas literature describes numerous cases with cardiac and vascular diseases, and especially coronary occlusions in civil pilots as causes of aircraft accidents (3, 6), such catastrophic events are relatively rare in military aviation.

In the following case we were able to determine a disease of the coronary arteries in a 36-year old Starfighter pilot through histologic examination. While pulling up after a bombing mission over a firing range, his aircraft made contact with the ground and crashed.
Microscopic examination of the cardiac muscle in the killed pilot showed a foci-like interstitial myocardial fibrosis with disseminating cardiac callosities. An atherosclerotic degeneration of the coronary arteries was also discovered. The arteria coronaria sinistra in particular revealed a pronounced constricted sclerosis of the vessel wall with a narrowing of the lumen amounting to 75 %. The intima showed considerable thickening, sclerosis and hyalinization. In places larger foam-cell granuloma and atheromatous embeddings with deposits of blue-stained calcium with whetstone-shaped blank spaces of colesterin crystals have been observed. According to these histological cardiac findings, G-forces as encountered during the flying maneuver performed had to constitute a considerable stress on the heart, which could have resulted in restricted blood circulation in the brain. This might have caused the delayed pull-up of the aircraft after the bombing.

In the case of a Starfighter pilot aged 37 years, whose aircraft had crashed because of purely technical reasons, the macroscopic examination could already furnish evidence of pad-like yellowish embeddings in the vascular walls of the coronary arteries with a distinct arteriosclerosis of the abdominal aorta and of the pelvic arteries. Two months before the accident occurred, medical examination of the pilot indicated an elevated blood pressure after resting. A histological examination of the heart showed intima insudations in the coronary arteries, however, with only negligible congestion of the lumen.There was neither callosity nor necrosis in the myocardium. The abdominal aorta and the pelvic arteries, on the contrary, showed gross lipoidosis and atheromatosis with foci-formed protrusions into the lumen and sedimentation of fat droplets in the vascular wall. With further progression of the arteriosclerotic process the vascular alterations would doubtlessly have led to the disqualification of this pilot for military flying within a foreseeable period of time.

Occasionally, communicable diseases are also uncoverd during histological examination. A special problem in our flying personnel, for example, is posed by coccidioidomycosis (2). This fungal infection with symptoms having clear parallels to pulmonary tuberculosis, is endemic in the southwestern part of the United States. Since soldiers of the Bundeswehr are being trained in these regions, there is the possibility of them contracting this disease by breathing spore-infested dust. Therefore coccidioidin tests and histoplasmin tests as well are performed in all soldiers returning from the USA.

A 34-year old pilot crashed fatally in his aircraft, type F-104G, after making contact with trees. Only small pieces of lung tissue could be secured clear of the thorax. A histological examination of the pulmonary tissue revealed concentrations of epitheloid cells, of lymphocytes, granulocytes and histiocytes, in fibrous scarred areas. These were evidently residual granuloma of a pre-existing coccidioidomycosis. After an intensive search, we found a typical double-contoured sporocyst embedded in dense perivascular fibrous tissue with clearly visible endospores. There was evidence of hyaline thickening in parts of the pulmonary pleura.
Some ten years ago this pilot had suffered an acute pulmonary coccidioidomycosis during training in the USA. In the years thereafter he repeatedly complained about inflammation of the nasal mucosa. There is a possibility that his efficiency had been reduced by such symptoms. In consequence pilots having been exposed to an infection with coccidioides immitis, with or without acute symptoms, require special control and surveillance by Flight Surgeons, since the onset of allergic and vegetative symptoms on one hand and re-activation of coccidioidomycosis foci during reduced immunity on the other may cause an impairment of flying performance.
The discovery of a nervous disease in a pilot through pathological and histological examinations is surely an exception (1). During the recovery maneuver in the course of a simulated attack on a concentration of tanks, the tail section of an F-104G came in contact with the ground and the aircraft exploded. The 26-year old pilot suffered grave mutilations. At autopsy the medulla spinalis, pars cervicalis showed two cavities of oval shape with a longitudinal diameter of approximately 1 mm each to the right and left of the central canal. The cavities gave a stamped-out impression and displaced the posterior and likewise the anterior commissure. This is the phenomenon of syringomyelia. Special staining for glia-tissue according to the method by HOLZER furnished evidence of the cavities being surrounded by a dense wall of neuroglia fibers. After the preparation of serial cuts it was found that cavity formation alternately extended throughout the entire intumescentia cervicalis clear down to the upper segments of the pars thoracica. The nervous dysfunctions to be expected at this stage of the disease have probably had a bearing on the fact that the pilot could not pull-up in time.

The findings presented here are illustrative of the utmost importance of histological examinations of all vital organs of aircraft victims for the clarification of aircraft accident causes.

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DISCUSSION

McMEEKIN: *Considering the incomplete examination of many fatalities when there are (a) inexperienced investigators, (b) fragmented and incomplete bodies, and (c) pre-existing disease conditions that are difficult to diagnose post mortem, do you believe that there may be a significant number of accidents resulting from undetected medical causes? If so, would you comment on the potential magnitude and significance of these factors?*

APEL: Especially for points (b) and (c), there is a possibility of undetected medical causes, but it is difficult to estimate the potential magnitude and significance of these factors. On the other hand, it is often difficult for the aviation pathologist to convince the investigation board of the importance of these findings. It is necessary that the role of the aviation pathologist be defined in the standardization of aircraft-accident investigation. STANAG 3318MED should be revised to include an aviation pathologist as a permanent member of the investigation board of a fatal-aircraft accident.

THE ASYMPTOMATIC "SILENT" MYOCARDIAL INFARCTION AND ITS SIGNIFICANCE AS POSSIBLE AIRCRAFT ACCIDENT CAUSE

by

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SUMMARY

There are numerous reports about myocardial infarction in pilots during flight respectively afterwards. Our observations relate to two cases in which pilots - 33 and 43 years old - complained about retrosternal pains of short duration (1 minute) respectively nausea as encountered in hypoxia incidents. Since there was no subsequent pain, there was no cause for an examination by a physician so that the pilots continued their flying duty. After an interval of 10 months respectively 1 month the ECG taken during the periodic flying fitness examination revealed the symptoms of a myocardial infarction suffered by the respective pilots. In consequence these pilots were grounded. In a third case a 37-year old pilot died of a natural death. - Failure of coronary circulation resulting from hemorrhagic pneumonia. In the course of the necessary post mortem examination a secondary finding revealed myocardial infarction; in spite of numerous control examinations, ECGs failed to show this diagnosis. The pilot had never indicated any symptoms suggesting myocardial infarction. After a detailed presentation of the clinical findings the import of these symptom-lacking "silent" myocardial infarctions as possible cause for aircraft accidents is discussed.

Coronary occlusion respectively myocardial infarction are relatively rare as cause of sudden death in street traffic. To the same extent this also applies to aviation. Whereas routine intensive health control is not mandatory for vehicle operators, it is part of a routine procedure in international aviation. In spite of this fact myocardial infarction may occur in flying personnel. International literature contains numerous reports on cardiac infarction in pilots occurring in-flight or shortly thereafter. Thus REIKHARD and MOLER (1967), SCHEINMANN (1968), and HEMMING (1970) have reported on myocardial infarctions observed in pilots. In 1974 RENEMANN of the Medical University Hospital in Freiburg published a comprehensive survey on Anglo-American literature concerning "Fatal Aircraft Accidents and Fatalities in Flying Operations Involving Cardiopathic Pilots up to 1971". In all these cases cardiac causes were diagnosed post factum as having been responsible for the accident sequence of events or they were established in post mortem examinations.

In addition to these myocardial infarctions with their sometimes dramatic course there are those with few or without symptoms, that means clinically "silent" ones, which at the earliest are diagnosed from the ECG during the next periodic flying fitness examination.

This paper presents observations concerning two pilots in whom a myocardial infarction was diagnosed during a flying fitness examination. In another pilot, who suddenly succumbed because of cardiac failure during a hemorrhagic pneumonia, post mortem examinations revealed as a secondary finding on old myocardial infarction unknown before.

Case 1: During a routine medical examination to assess military flying fitness, a 43-year old pilot stated that he had probably suffered a myocardial infarction some time ago. An ECG performed in the subsequent clinical examination verified an anterior-wall infarction, stage II, with still incomplete scarring. Save this objective finding the pilot subjectively was without any complaints whatsoever. The case history contained merely information about an appendectomy and two affections caused by gastritis. The pilot was a smoker consuming 15 - 20 cigarettes daily. In addition an overweight of at least 5 kg related to his height of 169 cm was found.
Thorough medical questioning under special consideration of the incurred myocardial infarction revealed that a few weeks prior to flying fitness examination the pilot had become aware of a peculiar state after a flight. He interpreted this to be the result of a disturbance in oxygen supply in the sense of hypoxia. Aside from a request for a technical inspection of the oxygen system no importance was attributed to this incident at that time, and a medical examination was not deemed necessary. Being a test pilot this aviator was exposed to excessive flying stress. The case history showed no sign which might have possibly pointed to a threatening myocardial infarction.

Case 2: An ECG during an ergometric workload of 125 Watt in a medical flying fitness examination revealed evidence of a previous anterior septal infarction in a 33-year old pilot. Three months later cardiac catheterization and coronary angiography during selective demonstration of the left coronary artery indicated a stenosis of the ramus descendens 99% below the origin of the first septum branch. Earlier periodic flying fitness examinations had shown no disorders, with the exception of colds. There were no pathologic findings. Only an overweight of approximately 10 kg was noted.
After the coronary occlusion was ascertained, detailed questioning of the pilot proved that 7 months before the myocardial infarction had been recognized, i.e. 4 months following the last flying fitness examination, he, after an F-104G flight, had noticed a short pain lasting about 1 minute in the left part of the thorax respectively posterior to the sternum. These experiences were said to have

repeated themselves two to three times independent of flying. Because he had failed to attach any importance to these short-term disorders, he did not think medical examination necessary, but reduced his smoking habits from a previous amount of up to 40 cigarettes a day.

It is of special implication that both pilots continued their flying duties over a period of one month respectively seven months after the observation of an incident which they took no heed of, resulting in myocardial infarctions. Aggravating symptoms which could have pointed to the incurred myocardial infarction, did not become manifest in the interval preceeding the next periodic flying fitness examination.

Case 3: A 37-year old pilot was found death in his quarters in April 1975. Because the cause of death was unknown, an autopsy was ordered which revealed coronary circulation failure resulting from hemorrhagic pneumonia. Furthermore the following findings were established independent of any causal connection with the cause of death:

Advanced atheromatosis and arteriosclerosis,

Pronounced arteriosclerosis of the coronary vessels with severe stenosis of the ramus descendens of the A. coronaria sinistra,

Infarction scar having the size of a 2-Mark-piece in the anterior wall of the left ventricle,

Moderate pulmonary edema

Description of Macroscopic Findings: Having a cardiac weight of 450 grams, predominantly found in sporting subjects, the epicardium and endocardium were without pathological findings, the cardiac walls were tender and intact. The course of the coronary vessels conformed to the normal. Compact bed-like wall embeddings partly constricting the vessel lumen were found in all coronary regions. Below the origin of the ramus descendens intraventricularis anterior of the left coronary artery there was a vessel stenosis caused by a very compact embedding. Immediately in front of this spot there was a slight aneurysmatic dilatation of the coronary artery. A complete occlusion - recent or older - could not be found anywhere.

Description of Microscopic Findings: The histological examination of the myocardium, particularly at the site of infarction, shows the alterations typical of myocardial infarctions, namely connective tissue lacking in nuclear mass and rich in fibres with sporadic vascular proliferation and absence of inflammation cells. The incised vessels revealed a moderate thickening of the walls. The pilot's case history listed an operation for inguinal hernia and a catapult ejection from an F-104 on 12 March 1971 causing infraction (Compression fracture) of the left calcaneus. Syphilis - stage 2 - determined in 1964 was cured after appropriate treatment in 1967. Beyond this, no further information was found which would have pointed to infarction. - In this context it is of interest, that the pilot's father had once met with myocardial infarction. Having a height of 183 cm the pilot weighed 87,0 kg; as a smoker his daily consumption was 15 - 20 cigarettes; no particulars are available concerning his sports activities. From the annual ECG-tracings on hand from 1957 through 1974 no indications for infarction may be found. Blood lipid determination performed in the year before his death revealed a pronounced elevation in cholesterine and triglyceride.
Since 1957 the pilot had accumulated the following flying hours on aircraft types indicated:

F-104	1.694:00
T-33	250:05
Other jet A/C	583:35
TOTAL:	2.527:00
P-149	118:25
Do-28	1:40
Other prop A/C	148:40
Total:	268:45

At this time you will excuse me from going into the details of the causality relating to the infarction as well as the special diagnostic deliberations in connection with the incurred and cured syphilis. It may suffice to say that the rarely observed gummatous myocarditis with its callous foci could have shown irregularities in the electrocardiogram.

DISCUSSION

From the casuistic contribution on three myocardial infarctions only discovered several weeks after they had occurred respectively not at all, indications are that coronary heart disease without or with only very discrete symptoms renders prevention methods very difficult or nearly impossible. Under the ever present stress of flying duty the occurrence of myocardial infarction in the form described above must be reckoned with at all times in predisposed pilots. This implies latent danger to flying safety, especially in private and military aviation, whenever the aircraft is operated by one pilot only. In commercial aviation, on the other hand, i.e. in passenger and freight transport and also in military transport and passenger operations, the presence of a co-pilot in addition to the first pilot is mandatory.

The survey of the state of health and the execution of possibly required preventive measures in pilots and other aircrew is the responsibility of the flight surgeons. They also conduct the periodic physical examinations at an interval of twelve months or have them initiated. - In the German Air Force an important factor in prevention is the constant physical presence of the flight surgeon in the Wing and the resultant close contact with the pilots, which often extends to include their dependents. This contact and the mutual relationship of confidence and trust based on it ease the tasks of the flight surgeon in the Federal Armed Forces considerably and contribute to

avoid a possible jeopardy of *flying safety*.
In civil - that is private and commercial - aviation, however, the personal contact with the flight surgeon is essentially limited to the routinely performed control examinations. In case of illness the family doctor, who is hardly familiar with aviation medicine, is mostly consulted. This habit incorporates the danger that illnesses occurring during flying fitness examination intervals as well as perhaps remarkable clues - surely without intention - do not find the attention necessary in assessing flying fitness, or remain unknown.

The three observed cases of "silent" myocardial infarction emphasize once more the importance of close personal contact and mutual relationship of trust between pilot and flight surgeon in the prevention of coronary heart disease. As a sort of family doctor the flight surgeon is supposed to have intimate knowledge of the psychosocial and somatic conditions of "his" pilots (i.e. coronary risk factors and specific symptoms ignored by the pilot). He is in an excellent position to interpret signs and symptoms with a view towards coronary heart disease at an early stage and he is the one to initiate adequate diagnostic measures to exclude or confirm coronary heart disease.

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CORRELATION OF OCCURRENCE OF AIRCRAFT ACCIDENTS WITH BIORHYTHMIC CRITICALITY AND CYCLE PHASE

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SUMMARY

The occurrence of aircraft accidents on various biorhythmic phases of cycles was studied. Aircraft-accident data were obtained from the National Transportation Safety Board for general civil aviation and from the U. S. Army Agency for Aviation Safety for military accidents. The accidents were divided into two groups, pilot- and nonpilot-involved cases, using the causal factors given by the respective accident boards. No correlation could be found between the occurrence of aircraft accidents and either the critical period, the negative phase, or the peak days of the negative phase of the biorhythmic cycles. Data were evaluated by chi-square analysis when considering all three cycles or the physical and emotional cycles alone, and all were studied with a critical period of 24 or 48 hours' duration.

INTRODUCTION

The "Biorhythm Theory" was developed from contributions of Swoboda, Fliess, and Teltscher. It predicted that behavior in terms of physical, emotional, and intellectual performance was influenced by cyclic variations. The work of the above authors is summarized in Thommen's book (1). Briefly, there are three cycles of 23-, 28-, and 33-day duration that govern physical, emotional, and intellectual performance, respectively. Each cycle is described by a sine curve composed of a high or positive phase, a low or negative phase, and nodal points where the curve crosses the abscissa. Each cycle starts on the first positive phase at the moment of birth. The positive phases correspond to periods of better performance, the lower phase to periods of poorer performance, and the crossover or nodal points are termed "critical periods." The critical periods represent times of poorest performance and greatest susceptibility to accidents. Critical periods are usually defined to have a duration of 24 hours. Occasionally, 48- or 72-hour critical periods are found in the literature. Figure 1 presents each curve independently and appropriately identifies the critical 24- or 48-hour periods as well as high, low, and peak days of the positive and negative phases as used in this paper.

From this theory, accidents would be expected to occur more frequently on critical days, days when more than one cycle is critical, days when on cycle is critical and the others are in a negative phase, or when all cycles are negative. Some proponents of the theory believe that the two most important cycles are the physical and emotional cycles when considering causes of accidents. Finally, one would expect that accidents involving an element of human error would be most likely to correspond to biorhythmic criticality.

The most frequently used method for testing the theory is to test previous accident data for correlation with the critical and low periods. This is possible because knowing only the birth date of the individual involved enables accurate calculation of the state of each cycle on the date of the accident. The theory is most accurately tested when time of birth and accident are available. Frequently, time of birth is difficult to obtain and an average must be used.

Initial attempts to apply the theory to aircraft-accident data were summarized previously (2). Data by Woodham, see Thommen (1), Brady (3), Weaver (4), and Williamson (5) did indicate a possible role for biorhythms as a causal agent in aircraft accidents. Interpretation of these data was made difficult by small sample sizes, lack of clearly defined critical periods, and lack of appropriate statistical testing. Sacher (6) recently published a study of over 4,600 U. S. Navy flight accidents, all of which involved an element of pilot error and over 2,300 of which were termed "pilot-factor-only" by the accident board. He used appropriate statistical testing and a 24-hour critical period and found no significant deviation from random expected results. In a preliminary study (2) to this more extensive report, we also failed to find significant correlation between aircraft accidents and biorhythmic criticality or phase of cycle.

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*The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Air Force, of the Army, of Defense, of the National Transportation Safety Board, or of the Federal Aviation Agency.

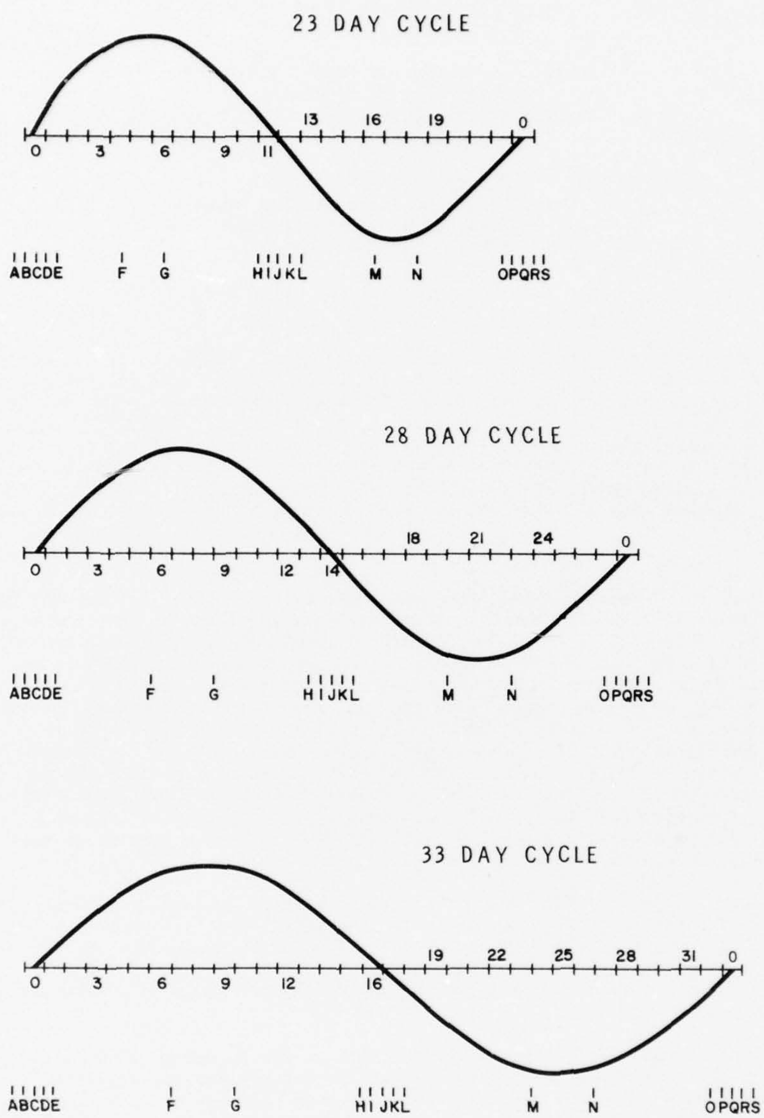

Figure 1. Physical (23 day), emotional (28 day), and intellectual (33 day) cycles. Letters represent the following in each graph: C, first cycle node or crossover point; B to D, 24-hour critical period; F to G, peak positive days; D to I, positive phase; J, second crossover point or half-cycle node; I to K, second 24-hour critical period; H to L, second 48-hour critical period; M to N, peak negative days; K to P, negative phase; Q, first crossover, new cycle; P to R, next 24-hour critical period; and O to S, next 48-hour critical period. (AFIP Neg. 75-9912.)

Two reports received recently have studied the correlation of biorhythms with industrial-type accidents. Mason (7) studied 13,285 lost-time accidents reported to the Workmen's Compensation Board of British Columbia during the 4-month period beginning 1 Jan, 1971. He used both the 11th and 12th days of the 23-day physical cycle and the 16th and 17th days of the 33-day intellectual cycle, which expanded his expected percentage from 20.37 to 26.59. He found that 3,584 accidents occurred on critical days, which is 26.98%. The study was carefully evaluated statistically, and no significant deviations from normal could be found. When a 5,259-member subgroup least likely to involve human error was studied, there were no significant deviations from the random biorhythm model or between the entire group and the smaller group.

Sanhein (8) studied 776 industrial and general accidents from 3 sources and found that 324 (41.7%) occurred on critical days. The critical period was apparently of 24 hours' duration. No breakdown as to type of critical days was given, and no statistical testing was reported.

MATERIALS AND METHODS

Source information was obtained from the files of the National Transportation Safety Board (NTSB) (9) and included the cause, date, and time of accident. Birth dates were obtained by manually searching individual accident records. U. S. Army data were obtained from computer files of the U. S. Army Agency for Aviation Safety, Fort Rucker, Alabama. Accidents were separated into groups based on accident-board determination of pilot involvement in accident causation. Accidents were listed as pilot involved when the NTSB data listed the first cause of accident as pilot factor. Accidents not so listed (mostly material failures) were considered as nonpilot involved. U. S. Army data listed pilot involvement as definite, primary or secondary role, suspected role, or not involved. The U. S. Army cases listed as suspected were not included in either of the other groups but were listed separately (199 cases) and included in the total number of cases.

The total days between dates on which the accident occurred and the birth date were calculated with either a Hewlett Packard HP 80 or HP 65 calculator. Total days between dates was then divided by 23, 28, and 33, using a simple program on the HP 65 calculator. An average time of birth of 12:00 hours was used. For accidents occurring outside the United States, the time of accident was converted from local time to Eastern Standard Time.

The critical period (day) was defined as a 24-hour period beginning 12 hours before the exact time that the curve crossed the abscissa. The first critical period in each cycle and the midpoint period of the 28-day cycle then started at 00:01 and ended at 24:00 hours. The midpoint critical period for the 23-day physical and 33-day intellectual cycles occurs at 24:00 hours on the 11th or 16th day, respectively. The critical period began, then, at 12:01 hours the 11th or 16th day and ended 24 hours later.

The hypothesis was formed that biorhythm is not involved as a causal factor in aircraft accidents. Chi-square analysis (10) was used to test the difference in observed and expected values. Chi-square tables were constructed with an over-all probability of 1.0, except Table VII. Each individual chi-square value as well as the total value was studied for significance. Individual values exceeding 2.71 or 3.84 were significant at the $p = 0.1$ and the $p = 0.05$ level, respectively. A probability of 0.1 was used throughout this report and was deemed adequate for initial screening of accident data, although a higher level of significance would be required to insure a relationship between biorhythms and accident occurrence.

Table I presents the expected percentage occurrence for each of the 27 possible combinations of positive, negative, or critical phases (+ - C) that could occur among three cycles. The ratios 10.5/23, 13/28, and 15.5/33 define a positive or negative phase, and the ratios 2/23, 2/28, and 2/33 define a critical day for the 23-day physical, the 28-day emotional, and the 33-day intellectual cycles, respectively. Data were evaluated by considering all three cycles, by considering the physical and emotional cycles only, and by defining the critical period as 24 hours or as 48 hours.

Correlation of phase of cycle to accident occurrence was done by studying the number of accidents that occurred on various combinations of positive and negative phases for all three cycles.

Finally, a correlation between accident occurrence and the peak days of the positive or negative phase in each cycle was investigated. The exact peak times occur at 5.75, 7.00, and 8.25 days for positive and 17.25, 21.00, and 24.75 days for negative phases in the physical, emotional, and intellectual cycles, respectively. Peak days were chosen to include either a 48- or 72-hour period surrounding the peak times. Peak positive days were as follows: days 5 and 6, physical cycle; days 6, 7, and 8, emotional cycle; and days 7, 8, and 9, intellectual cycle. Peak negative days were as follows: days 17 and 18, physical cycle; days 20, 21, and 22, emotional cycle; and days 24, 25, and 26, intellectual cycle.

RESULTS

<u>Correlation with biorhythmic critical days</u>

If biorhythm is involved as a causal factor in aircraft accidents, the most logical finding should be that a larger than expected number of accidents occur on critical, especially multiply critical days of the physical, emotional, and intellectual cycles. The number of accidents occurring on each possible combination of cycle phases is presented in Table II.

Table III presents data derived from both NTSB and U. S. Army cases subdivided into categories of pilot involved, noninvolved, and total. The first section of the table separates accidents as occurring on noncritical days, each combination of singly or doubly critical days, and triply critical days. The 12.82 total chi-square value for the smallest sample size (U. S. Army pilot-involved category) is the only total value that is significant. The second section of the table combined the individual singly

TABLE I

EXPECTED NUMBER OF ACCIDENTS OCCURRING ON CRITICAL AND NONCRITICAL DAYS IN THE BIORHYTHMIC CYCLES

CRITICALITY AND CYCLE	CYCLE PHASES P-E-I**	EXPECTED PERCENTAGE	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA* — INVOLVED: NTSB	USA	BOTH	NONINVOLVED (NTSB AND USA)	TOTAL (ALL CASES)
NONCRITICAL	+ + +, + + −,	9.9555	323.85	102.14	426.00	136.09	581.90
	+ − +, + − −,	each					
	− + +, − − +,						
	− + −, − − −						
	Total	79.6443	2,590.83	817.15	3,407.98	1,088.74	4,655.21
CRITICAL							
SINGLE	C + +, C + −,	1.8963	61.69	19.46	81.14	25.92	110.84
PHYSICAL	C − +, C − −	each					
	Total	7.5850	246.74	77.82	324.56	103.69	443.34
SINGLE	+ C +, + C −,	1.5316	49.82	15.71	65.54	20.94	89.52
EMOTIONAL	− C +, − C −	each					
	Total	6.1265	199.30	62.86	262.15	83.75	358.09
SINGLE	+ + C, + − C,	1.2846	41.77	13.18	54.97	17.56	75.08
INTELLECTUAL	− + C, − − C	each					
	Total	5.1383	167.15	52.72	219.87	70.24	300.33
DOUBLE P and E	C C +, C C −	0.2917 ea	9.49	2.99	12.48	3.99	17.05
	Total	0.5835	18.98	5.99	24.97	7.98	34.11
DOUBLE P and I	C + C, C − C	0.2447 ea	7.96	2.51	10.47	3.35	14.30
	Total	0.4894	15.92	5.02	20.94	6.69	28.61
DOUBLE E and I	+ C C, − C C	0.1976 ea	6.43	2.03	8.46	2.70	11.55
	Total	0.3953	12.86	4.06	16.91	5.40	23.11
TRIPLE	C C C	0.0376	1.22	0.39	1.61	0.51	2.20

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

**P = physical or 23-day cycle; E = emotional or 28-day cycle; I = intellectual or 33-day cycle; + = positive phase of cycle; − = negative phase of cycle; C = critical day.

TABLE II

OBSERVED NUMBERS OF AIRCRAFT ACCIDENTS OCCURRING ON EACH COMBINATION OF CYCLE PHASES

SEQUENCE NUMBER	CYCLE PHASES P-E-I**	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*					
		INVOLVED					
		NTSB	USA	BOTH	NONINVOLVED (NTSB AND USA)	SUSPECTED (USA)	TOTAL (ALL CASES)
1	+ + +	342	96	438	126	21	585
2	+ + -	315	101	416	138	24	578
3	+ - +	328	106	434	134	24	592
4	+ - -	337	120	457	125	13	595
5	- + +	318	100	418	139	18	575
6	- - +	293	90	383	161	21	565
7	- + -	325	91	416	141	23	580
8	- - -	299	103	402	123	16	541
9	C + +	62	20	82	18	1	101
10	C + -	57	17	74	22	6	102
11	C - +	58	26	84	29	7	120
12	C - -	63	22	85	25	4	114
13	+ C +	63	17	80	22	1	103
14	+ C -	47	22	69	21	1	91
15	- C +	51	16	67	21	2	90
16	- C -	48	25	73	17	1	91
17	+ + C	48	11	59	18	3	80
18	+ - C	42	9	51	27	3	81
19	- + C	48	5	53	22	2	77
20	- - C	56	16	72	20	5	97
21	C C +	8	1	9	2	0	11
22	C C -	7	1	8	3	1	12
23	C + C	11	3	14	4	0	18
24	C - C	12	1	13	5	0	18
25	+ C C	8	2	10	3	1	14
26	- C C	6	4	10	1	0	11
27	C C C	1	1	2	0	1	3
TOTAL		3,253	1,026	4,279	1,367	199	5,845

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

**P = physical or 23-day cycle; E = emotional or 28-day cycle; I = intellectual or 33-day cycle; + = positive phase of cycle; - = negative phase of cycle; C = critical day.

TABLE III

CHI-SQUARE VALUES DERIVED FROM COMPARISON OF OCCURRENCE OF AIRCRAFT ACCIDENTS ON CRITICAL AND NONCRITICAL DAYS OF THE PHYSICAL, EMOTIONAL, AND INTELLECTUAL CYCLES

CRITICALITY AND CYCLE**	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*				
	INVOLVED				
	NTSB	USA	BOTH	NONINVOLVED (NTSB AND USA)	TOTAL (ALL CASES)
NONCRITICAL (1-8)	0.44(-)***	0.13(-)	0.57(-)	0.00	0.42(-)
CRITICAL					
SINGLE					
PHYSICAL (9-12)	0.18(-)	0.66(+)	0.00	0.91(-)	0.09(-)
EMOTIONAL (13-16)	0.47(+)	4.67(+)	2.75(+)	0.09(-)	0.80(+)
INTELLECTUAL (17-20)	4.31(+)	2.61(-)	1.04(+)	4.00(+)	4.00(+)
DOUBLE					
P-E (21-22)	0.84(-)	2.66(-)	2.54(-)	1.11(-)	3.62(-)
P-I (23-24)	3.15(+)	0.21(-)	1.75(+)	0.80(+)	1.91(+)
E-I (25-26)	0.10(+)	0.93(+)	0.56(+)	0.36(-)	0.15(+)
TRIPLE P-E-I (27)	0.04(-)	0.95(+)	0.09(+)	0.51(-)	0.29(+)
TOTAL CHI-SQUARE	9.53	12.82	9.30	7.78	11.28
TABULAR CHI-SQUARE VALUE FOR EACH COLUMN ABOVE, p = 0.1, n = 7				12.02	
NONCRITICAL	0.44(-)	0.13(-)	0.57(-)	0.00	0.42(-)
CRITICAL					
ALL SINGLE P, E, and I	1.45(+)	0.82(+)	2.23(+)	0.07(+)	1.86(+)
ALL DOUBLE PE, PI, EI	0.38(+)	0.62(-)	0.02(+)	0.21(-)	0.04(-)
TRIPLE P-E-I	0.04(-)	0.95(+)	0.09(+)	0.51(-)	0.29(+)
TOTAL CHI-SQUARE	2.31	2.52	2.91	0.79	2.61
TABULAR CHI-SQUARE FOR EACH OF ABOVE COLUMNS, p = 0.1, n = 3				6.25	

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

**P = physical or 23-day cycle; E = emotional or 28-day cycle; I = intellectual or 33-day cycle; numbers in parentheses ( ) refer to left-hand column numbers of Table II and to the corresponding cycle phase in Table I, where source material is found.

***(-) = refers to fewer than expected numbers of accidents contributing to chi-square; (+) = refers to more than expected numbers of accidents contributing to chi-square.

and each type of doubly critical days into two groups and presents a total chi-square value based on 3 degrees of freedom. None of the total chi-square values is near the value of 6.25 required for significance.

Although not listed as a separate table, the total chi-square values derived by using each of the 27 possible combinations of phase of cycle shown in Tables I and II also result in 5 total chi-square values well below the significant level for a table with 26 degrees of freedom. Seven individual chi-square values of the 40 presented in the first section of Table III exceeded 2.71; none of the 20 in the second section of the table did. One of the seven resulted from fewer than expected numbers of accidents occurring on doubly critical days of the physical and emotional cycles. Using a 27-member chi-square table (data not shown, but can be calculated from data presented in Tables I and II), we found that 13 of 120 individual values exceed 2.71, 3 of these because of fewer than the expected number of accidents occurred on a particular type of critical day or more than the expected number occurred on noncritical days.

Thommen (1) himself--and, according to him, Schwing--beleived that the physical and emotional cycles were of primary importance in determining accident causation. All possible combinations of phases of these two cycles were investigated and the data presented in Table IV. In the first section none of the total chi-square values exceeded the level required for significance with 8 degrees of freedom. The only individual values exceeding the 2.71 level were 2.75 for fewer noncritical days (- -) than expected and 2.72 for more accidents occurring on (+ C) days in the total pilot-involved group, 3.98 for more (- C) days from U. S. Army pilot-involved group, and 2.92 from the total cases for fewer than expected numbers of doubly critical days.

In the second section the various types of noncritical, physical critical, and emotional critical are combined. One total chi-square value was significant (U. S. Army, pilot-involved group). The individual values for emotional critical (U. S. Army, pilot involved), emotional critical (both, pilot involved) and the same doubly critical value was significant.

Expanding the critical period to 48 hours resulted in 8-member chi-square tables (data not presented but would have same construction as Table III) with total chi-square values slightly less than 11 for both pilot- and nonpilot-involved groups. Both these total values, particularly the nonpilot-involved one, included individual chi-square values resulting from fewer than expected numbers of accidents occurring on certain types of critical days. There were 502 of 36.72% of the accidents occurring on critical days in the nonpilot-involved group and 1,629 or 38.07% in the pilot-involved group. The expected percentage is 37.78, and neither deviated significantly from this expected value.

Table V summarizes the individual and total chi-square values derived when the contribution of each of the three cycles--physical, emotional, and intellectual--was broken down into its three component parts--accidents occurring on positive, negative, or critical days. The data for the physical cycle do not include any total or individual chi-square values of significance. Significant chi-squares include one total value (6.15 for U. S. Army pilot-involved data) and one individual value (3.37, same source) for more accidents occurring on emotionally critical days than expected. Three of the individual chi-square values were significant in that more accidents occurred on intellectually critical days than expected.

Correlation of accident occurrence with phase of cycle

Data presented in Table VI were derived by breaking the data in Table II down into four categories: (i) all three cycles positive; (ii) any two cycles positive, the other either negative or critical; (iii) one positive, the others negative or critical; and (iv) all cycles negative or critical. This enables evaluation of the contribution of multiple phases of cycle on accident causation. Neither a total nor any individual chi-square value was significant. The total values for the combined pilot-involved group and for the total cases were extremely low, 0.82 and 0.33, respectively.

The chi-square values presented in Table VII were derived by comparing the number of accidents occurring on either peak negative or peak positive days of the three cycles. Both the observed numbers and the chi-square values are presented. Expected numbers can be computed by multiplying the total number of cases from each group by 2/23 for peak physical, 3/28 for peak emotional, and 3/33 for peak intellectual days.

There were no significant individual chi-square values for either peak positive or peak negative days of the physical cycle. Fewer than expected numbers of accidents occurring on peak negative days of the intellectual cycle resulted in a significant chi-square value of 3.22. There were more than expected numbers of accidents occurring on both peak positive and peak negative days of the emotional cycle, and both chi-square values were significant. One total chi-square value was significant but probably has little meaning since no trend toward more accidents occurring on either peak positive or peak negative days was evident.

DISCUSSION

Accident occurrence and biorhythmic criticality

If the biorhythm theory does play a part in accident occurrence, then statistical testing of observed occurrences should be highly significant. If one performs chi-square analysis of the data reported by Thommen (1, pages 31-34) and conducted by Schwing and Bochow, one will find that the values are extremely high. From Schwing's data a total chi-square of 850 would be computed for the following accident breakdown: 299 noncritical, 322 singly, 74 doubly, and five triply critical. For Schwing's data on death, 197 of 300 occurred on some type of critical day, and a chi-square value of 180 would be computed. From a statement by Thommen that triply critical days occur once per year, it is suspected

TABLE IV

CHI-SQUARE VALUES DERIVED FROM COMPARISON OF OCCURRENCE OF AIRCRAFT ACCIDENTS ON CRITICAL AND NONCRITICAL DAYS OF THE PHYSICAL AND EMOTIONAL CYCLES ONLY TO EXPECTED NUMBERS

	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*				
	INVOLVED				
CYCLE PHASE (+, -, or C) 23,28 Day (Source)**	NTSB	USA	BOTH	NONINVOLVED (NTSB AND USA)	TOTAL (ALL CASES)
+ + (1,2,17)	0.35(+)***	0.41(-)	0.04(+)	0.21(-)	0.01(+)
+ - (3,4,18)	0.44(+)	1.41(+)	1.35(+)	0.05(-)	0.68(+)
- + (5,7,19)	0.00	2.12(-)	0.44(-)	0.52(+)	0.04(-)
- - (6,8,20)	2.50(-)	0.33(-)	2.75(-)	0.70(+)	1.04(-)
C + (9,10,23)	0.01(-)	0.05(-)	0.04(-)	2.27(-)	0.95(-)
C - (11,12,24)	0.02(+)	1.39(+)	0.49(+)	0.26(+)	1.09(+)
+ C (13,14,25)	1.34(+)	1.70(+)	2.72(+)	0.05(+)	1.59(+)
- C (15,16,26)	0.01(-)	3.98(+)	0.79(+)	0.70(-)	0.01(+)
C C (21,22,27)	0.87(-)	1.78(-)	2.16(-)	1.43(-)	2.92(-)
TOTAL CHI-SQUARE	5.54	13.17	10.78	6.19	8.33
TABULAR CHI-SQUARE FOR EACH COLUMN ABOVE, p = 0.1, n = 8			13.36		
NONCRITICAL	0.02(-)	0.55(-)	0.23(-)	0.19(+)	0.02(-)
CRITICAL PHYSICAL	0.00	0.46(+)	0.12(+)	0.49(-)	0.00
CRITICAL EMOTIONAL	0.55(+)	5.45(+)	3.21(+)	0.19(-)	0.93(+)
DOUBLE CRITICAL P-E	0.87(-)	1.78(-)	2.16(-)	1.43(-)	2.92(-)
TOTAL CHI-SQUARE	1.44	8.24	5.72	2.30	3.87
TABULAR CHI-SQUARE FOR EACH COLUMN ABOVE, p = 0.1, n = 3			6.25		

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

** numbers in parentheses ( ) refer to left-hand column numbers of Table II and to the corresponding cycle phases in Table I, where source material is found.

***(+) refers to more than expected numbers of accidents contributing to chi-square; (-) refers to fewer than expected numbers of accidents contributing to chi-square.

TABLE V

CHI-SQUARE VALUES DERIVED FROM A COMPARISON OF OCCURRENCE OF AIRCRAFT ACCIDENTS ON POSITIVE, NEGATIVE, OR CRITICAL PHASES OF THE PHYSICAL, EMOTIONAL, OR INTELLECTUAL CYCLE TO EXPECTED VALUES

CYCLE, PHASE, AND SOURCE OF DATA**	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*				
	INVOLVED			NONINVOLVED	TOTAL
	NTSB	USA	BOTH	(NTSB AND USA)	(ALL CASES)
PHYSICAL					
+ (1-4,9,10,13,14,25)	1.36(+)***	0.52(+)	1.88(+)	0.16(-)	0.96(+)
- (5-8,11,12,15,16,26)	1.14(-)	0.72(-)	1.81(-)	0.70(+)	0.64(-)
C (9-12,21-24,27)	0.05(-)	0.09(+)	0.00	0.99(-)	0.17(-)
TOTAL CHI-SQUARE	2.55	1.33	3.69	1.85	1.77
EMOTIONAL					
+ (1,2,5,7,9,10,17,19,23)	0.16(+)	2.20(-)	0.14(-)	0.07(-)	0.12(-)
- (3,4,6,8,11,12,18,20,24)	0.33(-)	0.58(+)	0.02(-)	0.32(+)	0.03(+)
C (13-16,21,22,25-27)	0.19(+)	3.37(+)	1.64(+)	0.60(-)	0.17(+)
TOTAL CHI-SQUARE	0.68	6.15	1.80	0.99	0.32
INTELLECTUAL					
+ (1,3,5,6,9,11,13,15,21)	0.02(-)	0.20(-)	0.11(-)	0.15(+)	0.00
- (2,4,7,8,10,12,14,16,22)	0.59(-)	0.84(+)	0.05(-)	1.14(-)	0.62(-)
C (17-20,23-27)	6.16(+)	1.67(-)	2.35(+)	3.55(+)	5.66(+)
TOTAL CHI-SQUARE	6.77	2.71	2.51	4.84	6.28
TABULAR CHI-SQUARE FOR EACH COLUMN ABOVE, p = 0.1, n = 2			4.61		

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

** numbers in parentheses ( ) refer to left-hand column numbers of Table II and to the corresponding cycle phases in Table I, where source material is found.

***(+) refers to more than expected numbers of accidents contributing to chi-square; (-) refers to fewer than expected numbers of accidents contributing to chi-square.

TABLE VI

CHI-SQUARE VALUES DERIVED FROM COMPARISON OF OCCURRENCE OF AIRCRAFT ACCIDENTS ON VARIOUS COMBINATIONS OF PHASES OF CYCLE TO EXPECTED NUMBERS

	PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*				
	INVOLVED				
CYCLE, PHASE, AND SOURCE OF DATA**	NTSB	USA	BOTH	NONINVOLVED (NTSB AND USA)	TOTAL (ALL CASES)
ALL THREE POSITIVE					
(1)	1.02(+)***	0.37(-)	0.34(+)	0.75(-)	0.02(+)
ANY TWO POSITIVE					
(2,3,5,9,13,17)	0.07(+)	0.00	0.06(+)	0.03(-)	0.03(+)
ANY ONE POSITIVE					
(4,6,7,10,11,14,15,18,19, 21,23,25)	0.22(-)	0.18(-)	0.39(-)	1.75(+)	0.01(+)
ALL NEGATIVE/CRITICAL					
(8,12,16,20,22,24,26,27)	0.21(-)	1.34(+)	0.03(+)	1.39(-)	0.27(-)
TOTAL CHI-SQUARE	1.52	1.89	0.82	3.92	0.33
TABULAR CHI-SQUARE FOR EACH COLUMN ABOVE, p = 0.1, n = 3			6.25		

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

** numbers in parentheses ( ) refer to left-hand column numbers of Table II and to the corresponding cycle phases in Table I, where source material is found.

***(+) refers to more than expected numbers of accidents contributing to chi-square; (-) refers to fewer than expected numbers of accidents contributing to chi-square.

TABLE VII

CHI-SQUARE VALUES DERIVED FROM COMPARISON OF OCCURRENCE OF AIRCRAFT ACCIDENTS ON PEAK POSITIVE AND PEAK NEGATIVE DAYS OF THE PHYSICAL, EMOTIONAL, AND INTELLECTUAL CYCLES TO EXPECTED NUMBERS

		PILOT INVOLVEMENT IN ACCIDENT CAUSATION AND SOURCE OF DATA*									
		INVOLVED						NONINVOLVED		TOTAL	
	PHASE AND	NTSB		USA		BOTH		(NTSB AND USA)		(ALL CASES)	
CYCLE	PEAK DAYS	OBS.	X^2**	OBS.	X^2	OBS.	X^2	OBS.	X^2	OBS.	X^2
PHYSICAL	+ DAYS 5,6	286	0.03 (+)***	88	0.02(-)	374	0.01	128	0.70(+)	515	0.09(+)
	- DAYS 17,18	296	0.61(+)	80	0.95(-)	376	0.04(+)	104	1.86(-)	503	0.05(-)
EMOTIONAL	+ DAYS 6-8	342	0.12(-)	94	2.31(-)	436	1.10(-)	173	4.81(+)	628	0.00
	- DAYS 20-22	339	0.26(-)	94	2.31(-)	433	1.41(-)	170	3.78(+)	625	0.00
INTELLECTUAL	+ DAYS 7-9	288	0.20(-)	99	0.35(+)	387	0.01(-)	132	0.48(+)	537	0.06(+)
	- DAYS 24-26	271	2.07(-)	99	0.35(+)	370	0.93(-)	106	2.69(-)	490	3.22(-)
TOTAL CHI-SQUARE			3.29		6.29		3.50		14.32		3.42
TABULAR CHI-SQUARE FOR EACH COLUMN ABOVE, p = 0.1, n = 1							2.71				
p = 0.1, n = 5							9.24				

*NTSB = National Transportation Safety Board (9), cases from 1972 general civilian accidents; USA = U. S. Army, cases from U. S. Army Agency for Aviation Safety during period 1969 to 1975.

**OBS. = observed number; X^2 = chi-square.

***(+) refers to more than expected numbers of accidents contributing to chi-square; (-) refers to fewer than expected numbers of accidents contributing to chi-square.

that Bochow used a 48-hour critical period. Even so, based on the percentage of singly, doubly, and triply critical days reported, the total chi-square value (48-hour critical period) exceeds 11,000.

In the data presented here, from an evaluation of the contribution of all three cycles to accident occurrences on critical days, no total chi-square values were significant at the 0.05 level. This includes doing a complete set of tables (27-member chi-square tables) as well as the combined tables presented in Table III. The only total chi-square value significant at the 0.1 level was from the smallest sample size, the U. S. Army pilot-involved group. In this case the individual chi-square value for noncritical-day accidents was only 0.13, and a large share of the total chi-square resulted from fewer than expected numbers of accidents occurring on singly critical days of the intellectual and on doubly critical days of the physical and emotional cycles. In the data presented in the second section of Table III, when all singly and doubly critical days were combined, the total chi-square values were much less than the 6.25 required for significance. None of the individual chi-square values were significant.

If the contribution of only the physical 23-day and emotional 28-day cycle is analyzed, there is one total chi-square value that is significant at either the $p = 0.1$ or $p = 0.05$ level. This value, 8.24, results primarily from more than expected numbers of accidents occurring on singly critical days of the emotional cycle. There were fewer than expected numbers of accidents occurring on doubly critical days in data from all sources that contributed to each total chi-square value. The chi-square values for accidents occurring on all noncritical days were very low for data from all sources.

It is obvious from the chi-square value of 0.00 for critical days in the physical cycle (Table V) for the combined pilot-involved group that the criticality of this cycle was exactly as expected from the random model. The one individually significant value for accidents occurring on critical days of the emotional cycle occurred in the U. S. Army pilot-involved group (Table V), is not very high for the combined pilot-involved group, and is almost negligible for the total group. Three of the chi-square values for accidents occurring on critical days of the intellectual cycle were significant, one in the NTSB pilot-involved group, one in the nonpilot-involved group, and one in the combined group. This is also demonstrated in Table III, in which the individual chi-square value for the intellectual cycle was 4.00. In actual numbers it means that 15 more accidents occurred on singly critical days and 9 more on doubly critical days involving the intellectual cycle for the combined pilot-involved group. Of the total cases considered, 35 more accidents occurred on singly critical days and 9 more on doubly critical days of the intellectual cycle than expected.

The contribution of this one cycle was, as shown before, not significant enough to influence the total chi-square value. If we also consider the data from Sacher (6) for over 4,600 U. S. Navy cases, it is found that almost exactly the expected number of accidents occurred on intellectually critical days. A combined table presented previously (2), shows a resultant individual chi-square value of 0.88. Our conclusion is that the deviation from random found in this cycle is not significant. It seems unreasonable to assume that this cycle, which in our data accounts for almost all the deviation from expected values, is a causal factor of accidents.

In analyzing data by chi-square at the 0.1 level, it is expected that 1 in 10 chi-square values could exceed the value required for significance without invalidating the hypothesis. Of the individual chi-square values, there were 220 presented in Tables III-VII, or 355 if the total 27-member chi-square table is included (data not published here). Of these, 18 of 220 and 31 of 355 had chi-square values that exceeded 2.71. Tables III, IV, and V were primarily concerned with an evaluation of criticality and accident occurrence, and here the ratio was 15 individually-significant critical values of the 170 presented. Twelve of these values were derived because more accidents than expected occurred on critical days (or fewer than expected numbers on noncritical days). In summary, although there were a few more accidents occurring on various types of critical days, the over-all deviation is not significant.

Contribution of phase of cycle

Analysis of the contributions of positive versus negative phase for each cycle (Table V) revealed that there were no individual chi-square values of significance (for + or −, not critical). Data presented in Table VI, which summarizes the combined phase of cycle, also had very low individual and total chi-square values: only 0.82 for the combined pilot-involved group and 0.33 for the total cases. A triply negative day had no different effect than a triply positive day.

From the 27-member chi-square table (not presented but can be calculated from values presented in Tables I and II, lines 9 and 12), it can be determined that 63 accidents occurred on days when the physical cycle was critical and the other two were negative. There were 62 accidents occurring when the physical cycle was critical and the other two positive, the expected value for each type being 61.7. There were 63 accidents occurring on + C + days and 48 on − C − days (Table II, line 13 and line 16, respectively). There were 48 on + + C and 56 on − − C days (lines 17 and 20, respectively, of Table II). Again, no particular influence of phase of cycle can be demonstrated.

If negative phase of cycle is important, it might also be expected that accidents would occur more frequently than expected on days at the lowest point of each cycle, or peak negative days. Table VII presents this information. For the combined pilot-involved cases (4,279), no individual values were significant. In the noninvolved group, more accidents than expected occurred on peak positive and peak negative days of the emotional cycle. The only value significant when all cases were considered was the 3.22 value resulting from fewer than expected numbers of accidents occurring on peak negative days of the 33-day cycle. No evidence supporting peak negative days as a possible causal factor was demonstrated.

CONCLUSION

No significant correlation could be found between occurrence of aircraft accidents and biorhythmic critical periods or negative phases of the pilots. This was true when evaluating all three cycles or only the physical and emotional cycles and with either a 24- or 48-hour critical period. Although a few more accidents occurred on intellectual-critical days, when our data for pilot-involved cases are combined with Sacher's (6), this individual value is not significant. The number of individually significant chi-square values is less than the 10% that could occur using chi-square at the $p = 0.1$ level without invalidating the null hypothesis. The extremely low chi-square values derived when studying combined phases of cycle and the lack of correlation of accident occurrence to peak negative days strongly negates the hypothesis that the negative phase of cycle(s) is an important part of accident causation.

Although a safety-oriented program to continually brief pilots on biorhythms may, in fact, reduce accident rates, a similar program of frequent personnel briefings on safety without mention of biorhythms may have the same effect. Briefing biorhythms requires putting credence to a theory not proved by fact. Safety is of prime concern to all pilots. Briefing biorhythms is ill founded. Pilots are not more likely to have accidents on specific biorhythmic days.

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DISCUSSION

CHRISTIE: I agree that you have succeeded in dismissing one particular complex theory that relates rigidly to birthdate. Would you, though, extrapolate to dismiss all theories of biorhythms and their relationships to accidents?

WOLCOTT: No, the term "biorhythms" as used here refers only to this theory based on three fixed-length cycles starting at birth.

COOKE: If you had found a high degree of correlation, what would you have recommended?

WOLCOTT: I would recommend further investigation as well as at least some trial briefings applying the biorhythm theory to aviation safety. I would be particularly interested in the physiologic mechanism and would recommend research into this phenomenon.

McMEEKIN: A pilot may not believe you if you tell him that he will die if he steps on a sidewalk crack, but he will certainly be hesitant to do so. In the face of such overwhelming evidence that these noncircadian biorhythms are not related to accident causation, would you care to comment on the best ways to convince the pilots, or should we encourage them to "be safe" a few days each month?

WOLCOTT: I feel strongly that we can't afford, for the reason you allude to, to give pilots safety briefings based on "biorhythm." Telling them to be careful on critical days essentially lends credit to the theory, and pilots are likely to be induced into a type of cycle psychosis, i.e., to adjust their own feelings to the ups, downs, and critical periods. Dr. Yanowitch, a co-author of this paper, mentioned that a recent study in Israel demonstrated that accident rates could be directly related to the frequency of safety briefings. Frequent briefings resulted in fewer accidents. When briefings were stopped the accident rate rose, and this reversal was repeatable.

THE INTERPRETATION OF PERCENTAGE SATURATION OF CARBON MONOXIDE IN AIRCRAFT-ACCIDENT FATALITIES WITH THERMAL INJURY*

by

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SUMMARY

Victims of aircraft-accident fatalities suffering severe thermal trauma (as defined by second- or third-degree burns and/or percent saturation of carboxyhemoglobin (% COHb) values of 10 or greater) were abstracted from the records of the Armed Forces Institute of Pathology (AFIP). Of 518 cases accessioned from 1968 through 1974, 83 had either sublethal or no physical trauma. The mechanism of death in such cases may be (a) glottal spasm, bronchospasm, or acute edema of the upper respiratory passage, (b) cardiovascular collapse secondary to vagal inhibition, (c) acute thermal hyperkalemia potentiated by high levels of circulating cateholamines, (d) complete combustion of flammable material by on-board oxygen supplies, producing an intense fire without the production of CO, or (e) poisoning by other toxic products of combustion.

Representative cases are discussed to demonstrate and explain various combinations of physical trauma and burns with the observed % COHb concentrations. Suggestions are offered for the interpretation of these observations. As opposed to the experience of the civilian forensic pathologists with burn victims, in military aircraft accidents the % COHb is usually less than 40. Higher levels are seen only in the types of accidents involving large transport aircraft. Bronchial hypersecretion of mucous and frank coagulation necrosis of the bronchial epithelium may be a more sensitive indicator of the inhalation of products of combustion than is the presence of soot in the mouth or larynx, which may be introduced artifactually or agonally.

INTRODUCTION

Thermal trauma continues to be a leading cause of mortality and morbidity among those involved in aircraft accidents (1, 2). Thermal trauma is defined herein as injury resulting from the presence of a fire that is incidental to an aircraft accident. This injury may be either physical (burning) or toxic (the poisonous effects of the products of combustion). The Divisions of Aerospace Pathology and Toxicology of the AFIP serve as the central repository of the pathologic and toxicologic findings on deaths resulting from United States military aircraft accidents. This study draws from this experience.

MATERIALS, METHODS, AND RESULTS

The index years for this study are 1968 through 1974. All values of % COHb of 10 or greater than 10 in a fatality resulting from an aircraft accident were identified from the laboratory records of the Division of Toxicology of the AFIP. These were cross-checked against a computer-generated list of all aircraft-accident fatalities in which burns (or synonomous terms) were noted by a reviewer in the Division of Aerospace Pathology and coded as a diagnosis.

From 1968 through 1974, the Division of Aerospace Pathology accessioned 2,453 cases. Of these, 518 had thermal trauma as just defined. Tables I and II show distribution of these 518 cases by origin of case and by age.

Distribution of 518 Cases of Thermal Trauma in Aircraft Accidents

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*The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army, of the Air Force, or of Defense.

Table I. By Branch of Service

Branch of Service	Number of cases
U.S. Air Force	247
U.S. Army	167
U.S. Navy	46
U.S. Navy (Marines)	28
Civilian	27
Other	3
Total	518

Table II. By Age

Age (years)	Number of cases
0 - 14	1
15 - 19	14
20 - 29	287
30 - 39	124
40 - 49	39
50 - 59	13
Not Specified	40
Total	518

These 518 cases were then further investigated and classified by cause of death and the presence of carbon monoxide. This information is presented in Table III.

Table III. Distribution of 518 Cases of Thermal Trauma in Aircraft-Accidents by Degree of Trauma, Presence of CO, and Period of Post-Crash Survival.

	Classifica'ion Group	Number of Cases
I.	Traumatic deaths without elevation of % COHb, burns suffered either at or immediately following the crash (*)	338
II.	Death in hospital from sepsis or other complication of extensive second- or third-degree burns	91
IIIa.	Drowning without evidence of CO	3
IIIb.	Drowning with evidence of CO	2
IV.	Cases with (a) evidence of CO intoxication and or (b) severe second- and third-degree burns with either sublethal trauma or no trauma	83
V.	Other (**)	1
	Total	518

* No elevation of % COHb corresponds to a value less then 10% saturation.
** A case of CO intoxication caused by a defective helicopter heater.

The 83 cases of Group IV were studied and classified on the basis of the presence or absence of significant trauma. This information is presented in Table IV. Sublethal trauma is defined as (a) simple closed fractures of the extremities, (b) fractures of the ribs without penetration of the pleura, (c) vertebral compression fractures without spinal cord injury, and (d) superficial lacerations, contusions, and abrasions.

Table IV. Distribution of 83 Cases with Evidence of CO Intoxication and/or Severe Second- and Third-Degree Burns with Sublethal or No Trauma

Evidence of CO Intoxication	Number with No Trauma	Number with Sublethal Trauma
% COHb = 10 - 19	18	5
% COHb = 20 - 29	17	2
% COHb = 30 - 39	8	4
% COHb = greater than 40	5	2
Subtotal of cases positive for CO	48	13

Table IV. (Continued)

No CO present (% COHb less than 10)	13	9
Total	61	22

These 83 cases were finally tabulated (Table V) by type of aircraft % COHb.

Table V. Distribution of 83 Cases with CO Intoxication and Sublethal or No Trauma by Type of Aircraft Involved and % COHb

Type of Aircraft	Number of cases	% COHb <10	10-19	20-29	30-39	>40	mean(*)
Single and two seater fighter/attack	18	4	7	5	1	1	20
Bomber	7	2	2	2	1	0	21
Helicopter	16	7	5	2	1	1	24
Light Civilian(**)	14	5	2	4	2	1	29
Heavy Transport	26	4	5	6	7	4	27
Not Specified	2		2				
Total	83						

* No significant difference between means at p less than 0.05.
** Gross weight less than 12,500 pounds.

The procedure developed at the AFIP for the determination of carbon monoxide uses gas-solid chromatography with a thermal conductivity detector. This method has been used for 15 years for the evaluation of specimens for the presence of carboxyhemoglobin (3, 4).

DISCUSSION

In the evaluation of the observations reported, certain limitations and deficiencies should be considered. Although service regulations require that autopsy reports on all U.S. Army aircraft-accident fatalities be forwarded to the AFIP, not all U.S. Navy and U.S. Air Force cases are reported. Army aviation is predominantly centered around the use of helicopters and fixed-wing aircraft with specialized flight characteristics. Injuries peculiar to accidents involving these types of aircraft may therefore be over-represented. Civil aviation fatalities are reported to the Institute only occasionally, at the request of the Federal Aviation Administration and the National Transportation Safety Board. Another bias in the data is the loss to tabulation of patients dying of complications of burns or traumatic injuries in hospitals that do not recognize and handle such cases as aircraft-accident fatalities and do not forward them to the Institute. There is a small group of cases in which the autopsy protocols have been reported to the Institute but on which the toxicology determinations were performed at another location and the results of this examination never forwarded. The methodology used may be of a "screening" nature and not adequate to meet the needs of aviation toxicology. Sixteen cases were in this category and were excluded from an initial 534 cases, yielding the 518 cases finally considered.

A more serious consideration is the exclusion of fatalities resulting from aircraft losses caused by hostile action. Autopsy information is not readily available on these personnel. Injuries from a fire in a helicopter that crashes because of the loss of a tail rotor are not necessarily influenced by the reason for such loss of control.

The figures in Table II reflect the age distribution of fatalities of Armed Forces personnel and a number of civilians. Two factors predispose to the occurrence of a large number of burns as a finding coincidental with severe trauma. One factor is high-speed impact with the ground, e.g., the result of improper judgment of altitude during bombing runs ("controlled conditions") or departures from controlled flight with failure to eject. The second factor involves helicopters, usually on the in flight segment of a mission during which catastrophic structural failure occurs precluding successful autorotation.

Fatalities in Group II, Table III, are mostly survivors of helicopter accidents in which the burns were sustained after the accident. With the recent emphasis on improved crashworthiness and in particular the adaption of crashworthy fuel systems, these cases have diminished in relative significance. The cause of death in these cases was either septicemia from colonization of surface burns, respiratory insufficiency arising from tracheal and pulmonary burns and pneumonia. The drowning cases (Groups IIIa and IIIb in Table III) are interesting because fire balls were observed at the time of impact, and this transient exposure was sufficient to elevate the concentration of % COHb over 10 in two of the five fatalities.

In this study concentrations of % COHb less than 10 are considered "normal." The primary endogenous source of CO is the metabolic degradation of hemoglobin (5), and the primary exogenous sources are industrial pollution and the smoking of cigarettes. Higher values are seen in cases of uncompensated hemolytic anemias (6) and in persons exposed to engine exhaust fumes in enclosed spaces (such as workers in underground garages and traffic policemen). It is often stated that % COHb values in heavy smokers may be as high as 10. Such a concentration is unusual. It requires a continuous and heavy consumption of cigarettes. A more usual range of values in smokers is 1.5 to 4.5. A recent report claimed to show that a cigar smoker, while inhaling, achieved a % COHb concentration of 18.5 (7). On a subsequent report, it was suggested that there existed a defect in the subject's metabolism of carbon monoxide (8).

When a fire follows an accident, it must not be assumed that the presence of COHb was due to the fire alone. The presence of severe injuries incompatible with life often helps in determining the issue of when the exposure to CO occurred. There are equivocal situations in which it would have been possible for the inhalation to have occurred prior to impact (Case I, presented later). Unless the pathologist works closely with the aircraft-accident-investigation team, the true significance of an elevated % COHb may pass unrecognized. It may be erroneously attributed to a fire after the crash with the victim unconscious and subsequently asphyxiated. The true cause of death may be missed and the true cause of the accident not recognized.

What may cause elevation of % COHb in aviation personnel? Cabin heat is often generated by an air duct surrounding a muffler or bleed air assembly. A defect in this system allows CO to enter the cabin. Similarly, a separate gasoline-fueled heater may malfunction. An unrecognized inflight fire may generate carbon monoxide. A defective firewall separating the crew from the engines may lead to introduction of CO, intoxication and incapacitation of the crew. The effects of CO poisoning are insidious and are additive to the effects of hypoxia, even at altitudes of 3,200 meters or below where it is not mandatory for the crew to use oxygen. At 3,200 meters the blood pO_2 is approximately 70 mm Hg and the percent oxygen saturation of hemoglobin approximately 87.

High concentrations of CO have been reported in the vicinity of the breech blocks of machine guns mounted on helicopters. Accidental ducting of turbine exhaust gases into cabin areas is uncommon and is usually considered and dealt with during initial air-frame design. Retrofits to the existing U.S. Army utility helicopters for purposes of masking their engines' infrared signatures furthur deflect the exhaust up and away from the cabin area. Only one case of inflight incapacitation was identified in this series.

Case I. A U.S. Army pilot took off in a light observation helicopter. Two and one-half kilometers from the departure end of the runway, from an altitude of 75 meters, the aircraft crashed into a hillside. The pilot received severe internal injuries that were not compatible with prolonged survival. The % COHb in his blood was 44. No burns were present. Careful examination of the wreckage revealed a defective heater assembly with a hole between the exhaust manifold and the muffler jacket assembly. A reasonable explanation for this accident is pilot incapacitation from CO intoxication because of a failure in the muffler assembly.

Reference to Table IV shows that among the 13 victims with elevated % COHb and sublethal trauma, there is a relatively greater proportion of cases with levels of 30 and higher (6 out of 13 = 47%) than among those 48 victims with no trauma (13 out of 48 = 27%; significant at $p = 0.05$). Most sublethal trauma consisted of fractures of the lower extremity that prevented timely escape and subjected the victim to intense fire in an inclosed space where a limited supply of oxygen might predispose to an enhanced production of carbon monoxide. In contrast with this, victims with lower levels of % COHb were often found some distance from the center of the fire, where there are more complete conditions of combustion. Case II illustrates this.

Case II. A 27-year-old man exited a DC-3 commercial airlines after a crash landing and was seen to be making his way along the wing. Fuel in the wing ignited and he was engulfed in the ensuing fireball. At autopsy there was charring, there were no serious traumatic injuries, and he had a % COHb of 17.

A particularly interesting group of cases consists of those with a % COHb less than 10 and who have either sublethal or no trauma. Such a situations contrasts with that seen in the civilian experience of forensic pathologists dealing with victims of fire. In these instances, levels of % COHb are often greater than 50 and often there is no evidence of severe burns. Indeed, one textbook of forensic pathology states, "... if there is no increase in HBCo over 5% then the deceased must be assumed to be dead before or at the moment the conflagration occurred" (9).

With respect to this, it is clear that for many of the victims whose % COHb was less than 10 (in Table IV), even these low values may be explainable because of the inhalation of products of combustion. Symptoms are usually not present at these levels, but because it is possible that a level less than 10 may not be related to a fire, we have used this as an arbitrary cut-off point. A flight surgeon or aviation pathologist would be wise not to dismiss a % COHb of 9 in the peripheral blood without an acceptable alternative not related to the accident.

Values of % COHb over 40 are unusual in military aircraft accidents. The population at risk is for the most part young and healthy, without diminished cardiovascular reserve, and levels of % COHb of 40 or less would not be expected to have an immediate asphyxial effect. What is the cause of death in such cases?

There has been recent interest on the toxic effects of CO on cellular metabolism that is not related to its combination with hemoglobin. CO also combines with the myoglobin of skeletal and cardiac muscle. To a lesser extent it also binds to the cytochrome respiratory enzymes. In an isolated perfused mammalian heart, Ingenito et al. (10) demonstrated a deterioration in performance after the preperation was perfused with a solution containing dissolved CO. Another experiment (11) indicated that the substitution of an equal volume of 100% COHb-saturated blood may be carried out untill a level as high as 50% is reached before toxic effects are seen. In vivo saturation of hemoglobin by CO involves a random involvement of the four hemoglobin chains that comprise a complete hemoglobin molecule. On the other hand, a preparation with 50% of its blood volume isovolumetrically substituted still has 50% of its hemoglobin molecules unaffected to react with and to carry oxygen. A preparation with a % COHb of 50 may have all of its hemoglobin molecules at least partially affected. Toxic effects of CO over and beyond asphyxiation are subject to speculation at the present time.

Concern has been expressed about the production of other toxic gases by incomplete combustion of organic materials within the structure of the aircraft. Cyanide is mentioned most frequently. One case, an accident involving a jet trainer on takeoff, was identified in this series. There were severe burns, a % COHb of 32, minimal trauma, and a blood cyanide level of 0.045 mg/100 ml. Determinations for cyanide are not routinely carried out. Low blood values are often difficult to detect. Concentrations of cyanide in splenic tissue are usually higher than in the circulating blood, and the spleen is a useful organ to sample in those cases in which cyanide is suspected to be a factor. Low levels may act synergictically with CO.

In evaluating cases without trauma, severe burns, and low or sublethal levels of CO, several anatomic observations are useful. It is necessary to establish the degree of intraoral, intratracheal, and intrapulmonary burns. Mucosal hyperemia, gross burning with loss of substance, and the presence of soot are points to note. Two important features to observe microscopically are: (a) the presence of copious amounts of mucus without the eosinophilic reaction associated with an allergic reaction and (b) frank coagulation necrosis of the superficial layers of the epithelium caused by heat. In such cases the lungs are often fluid filled, boggy, and hypocrepitant.

Case III. Three Navy aviators were taxiing their helicopter on the runway when a main rotor blade separated and the aircraft turned over and burst into flames. None of the crewmen suffered traumatic injuries and all were badly burned. The two crewmembers who had low values of % COHb (2.0 and 3.5) had no gross or microscopic evidence of intraoral or pulmonary burns. The third crewmember had a % COHb of 17 with burns and soot in the mouth but apparent sparing of the lower respiratory tract.

In cases of severe postmortem incineration, true intraoral burns must be distinguished from the artifactual introduction of soot and debris during the fire, removal of the remains from the wreckage, or transportation of the body to the autopsy facility. True antemortem injuries must be distinguised from injuries artifactually produced by fire. These include (a) collections of blood in the extradural space, mimicking a hematoma, (b) bursting fractures of the calva caused by intracranial production of steam, and (c) thermally induced fractures of long bones and thermal amputations.

What is the cause of death in aircraft-accident victims in whom are found (a) severe burns, (b) very limited trauma, (c) low or sublethal levels of % COHb and (d) little or no evidence of intra-pulmonary burns?

It has been postulated that there is a reflex glottal spasm triggered by an initial influx of hot gases. There is seldom evidence of such spasm at autopsy, but acute edema of the upper respiratory passages is occasionally seen, and it is well recognized that complete blockage of the airway can result from edema on an allergic basis within a matter of minutes.

Experiments on goats tethered within an experimentally produced fireball, conducted after World War II (12), demonstrated high venous levels of potassium shortly after the experiment was terminated. It was suggested that this came from acutely damaged red blood cells in the superficial body tissues. This acute thermally induced hyperkalemia could cause cardiac arrythmias and terminal ventricular fibrillation. This mechanism could be greatly potentiated by high levels of circulating catecholamines present at the time of the accident.

Neurogenic shock and reflex cardiac standstill resulting from vagal suppression of cardiac action are thought to be able to produce sudden death following massive stimulation of pain receptors. This can occur during the first minutes of a total body burn in an aircraft fire in which the victim is totally engulfed in a fireball.

High-performance jet aircraft and some transport types contain stores of liquid oxygen and apparatus for delivering it to the crew. On impact, if the regulators and distribution lines are damaged, oxygen pressurized to 300 psi might be delivered into the burning cockpit and cause complete combustion of flammable materials without production of carbon monoxide. An example of the varying degrees of combustion that can take place in an aircraft accident fire is Case IV.

Case IV. An Air Force T-29B crashed shortly after takeoff and burned. Impact was on gently rising terrain, and the aircraft had considerable distance in which to decelerate. The air frame remained relatively intact. The crew and passengers were strapped in and were thrown varying distances from the burning aircraft, together with their seats, or remained within the structure. None suffered severe traumatic injuries. All on board suffered severe burns, and all died in the crash except one survivor. Those who were in the area of the initial fireball had typically low % COHb (15, 18, and 11). Those some distance from the fireball had higher levels (37, 42, 53).

It might seem paradoxical at first that those in the center of the fire had lower levels of % COHb than those at the periphery, but this supports the observation that the primary cause of death in most of these cases relates to the thermal rather than the toxic properties of the fire. At the periphery of the fire these thermal effects are probably less severe because of lower fuel concentrations and convective cooling, which allows longer survival with a greater accumulation of CO and other products of combustion.

Finally, an extremely intense fire, perhaps fed by supplemental oxygen from the aircraft, and occurring in the enclosed space of a cockpit might increase the core body temperature 6 or 7 degrees F. and cause death from acute hyperthermia. It is more than probable that the true cause of death in these cases is a multiplicity of the above enumerated factors.

The investigator should take care in the collection of adequate postmortem samples. Even in severely charred bodies there may be sufficient core tissue in a semifluid state to allow the collection of an adequate blood sample for CO evaluation. In the absence of sufficient liquid blood, a 200-gram sample of lung or liver tissue or any available tissue with a liquid hemoglobin (blood) content will usually prove sufficient. Carboxyhemoglobin is relatively resistant to the effect of postmortem decomposition (13). Caution should be exercised in procuring "scoopings" of blood from a shattered thoracic cavity since significant contamination of such blood can occur during a postcrash fire that produces high ambient levels of CO.

Case V. The pilot of an Air Force F-100 crashed into the side of a hill during a routine training mission. He had severe mutilating trauma, and there was a vigorous postcrash fire. A sample of blood showed a % COHb of 17, and an intensive search was undertaken for deficiencies in the aircraft's heating and bleed-air systems. Only when a % COHb determination performed on blood extracted from a sample of lung yielded a value of 3% was it found that the "blood" sample was obtained from scoopings out of the thoracic cavity, which had been directly exposed to the fire.

Although complete postmortem examinations may be difficult to accomplish upon all of the victims of large commercial or military transport accidents, collection of a sample of blood for CO and alcohol determinations (in those circumstances where legal considerations permit it) is mandatory. Samples should be collected, where possible, from an intact cardiac chamber, by "milking" a femoral vessel or by collection and shipment of lung and liver for subsequent extraction of blood. Correlation of % COHb levels with traumatic and thermal injuries and with the relative locations of the deceased with respect to emergency exits may answer questions regarding the reasons for a particular victom's inability to escape from a wrecked and burning aircraft. This is turn may influence future designs so as to enhance survivability.

When all of these cases are tabulated, there remain a small number of cases in which the toxic effects of the fire seem to predominate in causing death. Only four such cases were identified in the present study.

Case VI. A passenger in the aforementioned T-29B (of Case IV) was found 30 ft. from the tail section. He had apparently unbuckled himself and crawled to this location. He had only focal second-degree burns, minimal trauma, and a % COHb of 56.

Case VII. An Air Force student pilot in a T-38 crashed upon landing. A fire started in the rear of the aircraft, and the pilot was unable to either jettison the canopy or otherwise extricate himself. When he was finally removed he had only slight burns, no physical trauma, and a % COHb of 72. This is consistent with an asphyxial death.

When the 83 cases of Table III, Group IV, are subdivided by the type of aircraft involved in the accident and the level of % COHb (Table V), the mean values of saturation (in those cases with 10% or greater) are seen to vary only in the range of 20 to 29%. When the percentage of CO saturation is further subdivided by aircraft type, it is seen that as the relative amount of habitable cabin space increases, in the order that the various types are listed, there is a relative preponderance of higher values of % COHb. Thus those aircraft with the largest amount of cabin space in relation to the total air-frame size (commercial transports and tankers) have a large proportion of cases with % COHb over 30. Those aircraft with the lowest relative volume (fighter/attack types) have the lowest proportion of such cases. It is tempting to speculate that the increased cabin volume allows time for the propagation of fires that produce lethal quantities of CO while providing some isolation to the crew and passengers from the direct physical effects of the fire.

Most aircraft accidents occur during takeoff and landing. Only 12 of these 83 fatalities occurred during the en-route phase of flight. Modern jet aircraft of all types have generally similar rotation and approach speeds. Despite this, the generally superior crashworthiness of military as opposed to civilian aircraft may be considered a factor in a number of civilian fatalities.

Case VIII. A civilian passenger aboard a DC-3 suffered severe second- and third-degree burns and was found at autopsy to have a % COHb of 47. Both ankles had been fractured during the crash by impact with the rear lower rail of the seat in front of him, and he was unable to escape from the burning aircraft.

These results generally extend the observations of Glantz et al. (14) and Dominguez (15) and confirm the studies of Blackmore (16). Glantz et al. reviewed 59 cases of aircraft-accident fatalities and found 15 of them to have elevated % COHb. Five cases were noted to have been alive at the time of the fire but to have had % COHb levels of less than 10. In an earlier paper one of us (Dominguez) commented upon those cases with burns, a paucity of physical trauma, and without an elevated % COHb and suggested several mechanisms to explain these cases. We mentioned shock, laryngeal edema, and

physical circumstances surrounding the fire leading to complete combustion without carbon monoxide production.

Blackmore's recent study (16) reflects modern aircraft and operational situations. Here also are several cases exposed to fire and with evidence of inhalation of hot gases (as evidenced by intra-tracheal soot) but with low levels of % COHb. Several possible explanations of this phenomenon are given: (a) inhalation being an agonal event, (b) postmortem sampling techniques, (c) complete combustion with negligibe production of CO. Possibility (b) is of particular interest, and a study on a series of aircraft-accident fatalities presenting the % COHb levels of blood collected from multiple sites and extracted from multiple tissues would be a welcome addition to the literature.

Blackmore also presents a preponderance of deaths associated with fire with percentages of COHb of less than 10 (approximately two-thirds of the sample) but makes no explicit statement concerning trauma in these cases. He very carefully discusses the relationship between bone marrow emboli, fat emboli, trauma, and % COHb.

The pathologic findings on 91 victims surviving for an extended period after the crash and fire (Table III, Group II) are interesting in themselves and will be the subject of a separate communication.

CONCLUSIONS AND RECOMMENDATIONS

Unlike the experience in civilian forensic pathology, where high elevations (greater than 40%) of COHb are the rule, the military aviation pathologist should expect to see generally lower values in victims of military aircraft accidents. This is because the intense nature of the fires fed by highly flammable fuel, the absence of large cabins in which the fire can become established and produce large quantities of CO; and the destructive cardiovascular, respiratory, and neurogenic effects of direct intense heat upon the human body do not allow for survivals longer than a few minutes. Thus in the typical military accident the fatal effects of fire are expressed more through physical than toxic means.

In large aircraft with greater cabin volumes and greater opportunities for propagation of fire, blood concentrations in the asphyxial range may be encountered.

When an aviation pathologist is called upon to evaluate a fatal case with little trauma, with burns, and with a markedly elevated % COHb resulting from the crash of a helicopter or fighter-type aircraft, the wreckage should be searched for evidence of inflight fires or malfunctions that may have led to CO intoxication. Although such cases are rare, they are the most fruitful ones for future aircraft accident prevention, the basic goal of aircraft-accident pathology.

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TOXICOLOGICAL ASPECTS IN THE INVESTIGATION OF FLIGHT ACCIDENTS

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SUMMARY

This is a report on the working methods of the German Flight Toxicology working group, some problems are presented beginning with the difficulties to obtain suitable material for analysis.

Positive alcohol results require a determination of the water content and a test of possible putrefactive processes. Comparing the various procedures for blood alcohol determination it is found that the enzymatic method can furnish high values differing from others. Gaschromatography identified some endogenous substances and putrefactive components respectively, some cases of joint occurrence are mentioned.
A publication is quoted which illustrates the disadvantages of the photometric determination of carbon monoxide in burned corpses. Extraction methods required for chromatographic separations of biological material are discussed and some disadvantages compared. Chromatographic techniques are only covered in excerpts.

Quoting from literature it is refuted that determinations of lactate would furnish evidence of hypoxia during a flight. In muscle tissue of flight accidents comprehensive glycolysis and corresponding increase in lactate could be observed.

The majority of flight accidents is caused by human failure. In the broadest sense the cause may be an intoxication or a secondary drug effect. It is the task of the flight toxicology working group within the division of aviation accident pathology to detect substances which might have decreased the efficiency of the pilot or his crew (such as alcohol, drugs and drugs of abuse respectively, substances used in aircraft maintenance) or substances originating from the accident itself (fuel, carbon monoxide, gases generated by fire). Examinations of this nature occasionally include a series of tests to determine the metabolism of drugs and the time they were retained in the organism. Frequently it is only the total of these findings which enables the physician to interpret the complex events culminating in a flight accident.

To accomplish these tasks the toxicologist, therefore, requires sufficient samples of urine, gastric content, hepatic-, renal-, and cerebral-tissue, pulmonary tissue and blood from the different parts of the body. In addition these samples should be clean. In most flight accidents, however, these requirements can not be met because of the condition of the corpses. Even the requests for immediate post mortem sampling with subsequent delivery to the toxicological laboratory as a rule can not be accomplished. Thus, the toxicologist as a minimum can only ask for chilled transport in well sealed containers. In order to successfully analyse the mostly small amount and not ideal material of its kind, apparatus having the highest sensitivity should then be available.

Some of the difficulties mentioned make themselves apparent in simple blood alcohol determinations and in the interpretation of the corresponding findings. We determine blood alcohol in fluids of pressed tissue, blood respectively chilled, homogenized, coagulated blood, and urine in an enzymatic manner, and in a gaschromatographic manner according to the head-space-method and according to WIDMARK, whereby unused dichromate is not re-titrated but photometrically recorded after KLING-MÜLLER (1).

Normally the method after WIDMARK provides the highest values of the three methods, but especially with autopsy blood this rule often does not apply. SCHLEYER (2) reports that 17% of the blood alcohol values stemming from the enzymatic method are above the corresponding WIDMARK values. Through his gaschromatographic analysis WEINIG (3) obtained lower concentrations than with the enzymatic method. Both findings were also verified in our laboratory. Obviously the ferments react to components in the autopsy blood.

The transport of blood for the blood alcohol determination should be accomplished in a separate, chilled container to which 0,5 to 1% sodium fluoride has been added, (see the results of PLUECKHAHN (4)), to suppress new alcohol generation. Escherichia coli and other coli bacteria, proteus species and clostridia as well as candida fungi are predominantly responsible for the formation and later decomposition of alcohol. An affection of the examination material sampled in flight accidents with these kinds can not be avoided. Even under sterile autopsy O'TOOLE (5) and collaborators were able to identify bacteria or fungi in 54% of their blood samples.

Positive results require a determination of the water content, since, according to GRÜNER (6) and BRETTEL (7), the alcohol content changes proportionally to the water content from a normal average of 80%.

To prevent erroneous positive findings, the withdrawal of blood samples from various parts of the corpse is not sufficient. Corresponding values in different samples will not entirely preclude putrefaction. Conversely, differing values in different samples from the same body are evidence of such putrefactive processes if the finding is not disproved by a determination of the water content.

It is easy to identify false positive values through several gaschromatographically established putrefactive alcohols in a sample or through demonstration of bacteria and fungi respectively. SCHWERD (8) reports on decrease in blood alcohol content even without the settlement of bacteria or fungi. He suspects enzymatic processes as being the cause of it. Such erroneous findings can best be avoided by transportable gaschromatographs now available and by analysis at the scene of the accident. The alcohol distribution in the body is equal throughout the post-absorbent phase with the probable exception of the frontal lobe of the brain. Blood samples from the thorax and heart do not lend themselves to alcohol determination because of possible gastric diffusion, nor does cardiac blood because of its high glucose content with a view towards alcohol production.

The presence of substances originating from flight operations and from the accident as such is mainly determined by gaschromatography. For this purpose venule blood is opened in a chilled container, and the sample taken is immediately sealed and analysed. In the course of such examinations methane, ethyl ether and ethyl acetate were determined and subsequently also found in the autopsy blood. As an extreme case venule blood should be mentioned, which, having merely been transported for four hours under room temperature, revealed traces of three putrefactive alcohols and ethyl acetate and ethyl ether 25 hours after sampling. During long-term control an increase of ethyl acetate with a simultaneous increase of ethanol through putrefaction was found. Other putrefactive components found by us are listed by WEINIG (9), LAUTENBACH (10) and others. The frequency of the alcohols determined by us, however, differs and some of them are absent altogether in our samples. Thus, contrary to literature, we frequently found n-butanol without n-propanol in rather fresh blood. It deserves mentioning that according to LAUTENBACH (10) acetone produced through putrefaction will always occur jointly with isopropyl alcohol.

What BLACKMORE (11) said in 1969 applies to the determination of carbon monoxide in blood. His statements were substantiated by the findings of IFFLAND (12) who always found more carbon monoxide (up to 30%) in burned corpses with the photometric method than with the gaschromatographic method. In CO-free blood he was able after boiling to actually identify CO by photometry. Dictated by apparatus on hand we require a hemoglobinometry by means of X-ray fluorescence in values exceeding approximately 3% CO-Hb. This technique, which is free of losses, is also used by us in preliminary tests of blood and urine to determine bromine-containing sedatives and hypnotics respectively. We also test gases generated by fire from synthetic substances, on whose toxicity MOHLER (13), POHL (14) and YAMAMOTO (15) have reported.

For the determination of drugs or metabolites, tissue is homogenized in a solution of tartaric acid and ammonium sulfate according to LANG (16) and extracted by ethanol. Tungstate according to STREET (17) is only used for deproteinizing, if no basic extract follows, since otherwise weak basic drugs may enter the acid extract and precipitated protein will bind considerably more drugs.

Normally there is no pre-purification of blood, homogenized matter and urine, for example with hydrocarbons, to remove fatty acids and re-extractions of acid or basic extracts to avoid diminishing of yields. The alkaline extract will not be subdivided, an ammoniacal extract will, however, be made. Ether serves as an extraction agent, while chloroform is used in any case in the secondary extraction. For evaporation the extractions are combined. The acid components of urine are extracted by adding salt; the hydrolysis, also of blood or homogenized matter, is effected by boiling for 10 minutes after having added the same volume of concentrated hydrochloric acid. In specified examination requests an alkaline extract of blood is carried out according to GOLDBAUM, an acid extract according to VALOV (18). Ethanol after BAMANN-ULLMANN (19) is first added to gastric contents. The evaporation of the alkaline extracts finally is carried out by adding methanolic hydrochloric acid to avoid evaporation losses.

Paper chromatography is often preferred due to its higher sensitivity in comparison with thin-layer chromatography. Furthermore, the separated substances are easier extractable for identification by means of IR-spectra. For drug screening the following sprays are routinely used: Mercuric salt with diphenyl carbazone, iodoplatinat, Dragendorff's test, bromocresol-green, FPN-test and potassium ferricyanide with ferric chloride. Numerous determinations, however, are carried out using thin-layer plates or gaschromatography without temperature program. Chemical modifying is only carried out for specific problems. During gaschromatographic tests for barbiturates we presently methylate exclusively with trimethylanilinium-hydroxide, however, for these substances we are modifying to column adsorbtion chromatography with UV-detection. For more than a decade possibilities were discussed to determine in-flight hypoxia in the accident victims and after landing respectively. As the most frequent method an analysis of lactate, preferrably with the brain as examination material, was performed. After reviewing a majority of literature it may be concluded that such findings are without sound practical basis. While VAN FOSSAN (20) establishes the end of lactate formation in the brain to the minute in post mortem examinations, McBURNEY (21) in animal tests was unable to observe a standstill even after 48 hours. VAN FOSSAN (20) finds corresponding lactate values in approximately 90% of his clinical hypoxia cases, McBURNEY (21) after 15 minutes of hypoxia in 30% of the experimental animals.

Both authors call attention to the fact that the conditions in the material of most flight accidents may be considerably altered by tissue decomposition, putrefaction, access of air, time after last meal intake and duration of hypoxia. Thus, McBURNEY (21) in animal experiments did not observe any lactate formation in muscles in post mortem examinations. On the contrary we, in material of flight accidents, found an increase of lactate in muscles of several 100%. FRANKS (22) reports on a comparison of white brain substance with a gray one and higher lactate values in the latter. During the investigation of a flight accident we received a converse ratio.

The strongest argument against the possibility to prove hypoxia after flight accidents in our opinion is the volumenous statistical material by DOMANSKI (23) covering 1258 flight accidents. Lactate determinations in the blood after hypoxia incidents can not be used as evidence. According to MÜLLER (24) lactate in the blood is subject to catabolic effects under light work in 10 minutes, i.e. an increase caused by hypoxia can no longer be measured at the time of blood sampling. Values derived from muscle work of ever changing magnitude and lactate generated during transport are, however, measured.

To prove hypoxia in flight operations, no other measuring variables are available, which depend on the respiratory chain without being dependent on glycolysis.

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RECENT AGRICULTURAL AIRCRAFT ACCIDENTS IN THE UNITED KINGDOM

BY

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SUMMARY

After many years of fluctuation, the incidence of agricultural aviation accidents has shown an upward trend during the past eight years. The accidents have been analysed for cause, geographical distribution and frequency. The probability of an accident occuring increased indirectly with age of the pilot and directly with his experience. Pilot error was the direct cause of the majority of accidents. Improved education and legislation would help to reduce the exposure to toxic chemicals. No direct inference could be made relating the accidents studied to exposure to toxic chemicals.

INTRODUCTION

Records kept since 1956 show that there has been a great fluctuation in the number of agricultural aviation accidents over this period. Table 1. There have been periods of high accident activity followed by troughs of calm but during the last seven years the accident rate has risen steadily. There has been an increase in the hours flown by the agricultural pilots during these years. The steady increase in the ratio of accidents per annum to hours flown in agricultural aviation is against the general trend in commercial aviation. The number of aircraft available for agricultural aviation has risen from 53 aircraft in 1972 to 87 aircraft in 1975. Fixed wing agricultural aircraft usually average 450 hours per annum and rotary winged aircraft 300 hours per annum.

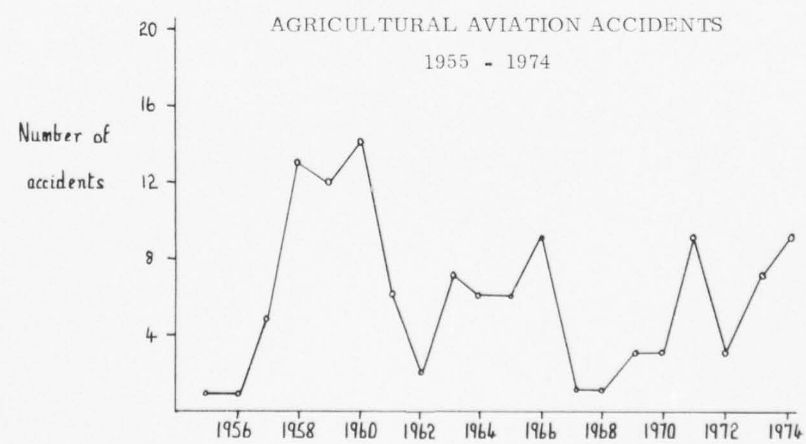

Table 1

The United Kingdom has a widely distributed agricultural industry with the East and South East being the main cereal and root crop areas. Most aerial spraying is done in these areas whose topography is mainly flat, open countryside with small fields surrounded by hedges and bush fences. The flying is confined largely to hedge hopping and many accidents are caused by contact with the ground or ground obstacles. It is not surprising that the majority of accidents have occured in these geographical areas.

Crop Spraying is seasonal and has many tasks including fertilizer distribution and pesticide application. This seasonal work is reflected in the monthly distribution of accidents. Table 2. The warmest months in the United Kingdom are June to September, when maximum growth of both plants and insects occurs. The insects must be removed quickly and most work is therefore during this period.

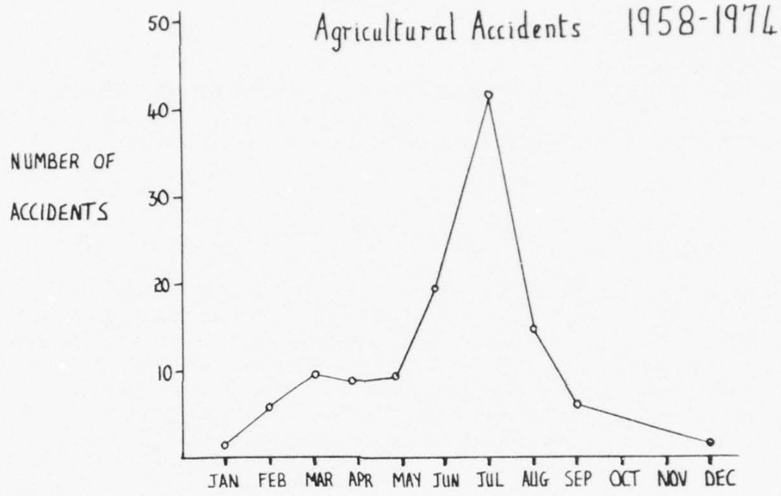

Table 2

The time of day that an accident occurs appears to follow the typical British working habits. Table 3. Conditions are seldom right for spraying in the early morning and work builds up during the day, with a break for coffee and another for lunch. The peak accident rate occurs immediately after lunch after which it tails off gradually with a dip during mid-afternoon.

The high accident rate in early afternoon could reflect the rise in air temperature at this time of day, the lack of concentration that occurs after a good meal and the natural build up of work in a normal day. The effects of fatigue and the possible effects of toxic pesticides are important factors.

The spillage of diluted chemicals during fast reloading is usually minimal, but there is danger that repeated spillage will cause a build up of concentrated chemical by evaporation. The action of the pilot climbing in and out of the aircraft is bound to involve handling the surface of the aircraft and thus contamination can occur. This type of contamination is more serious in pilots who smoke or who wear little protective clothing.

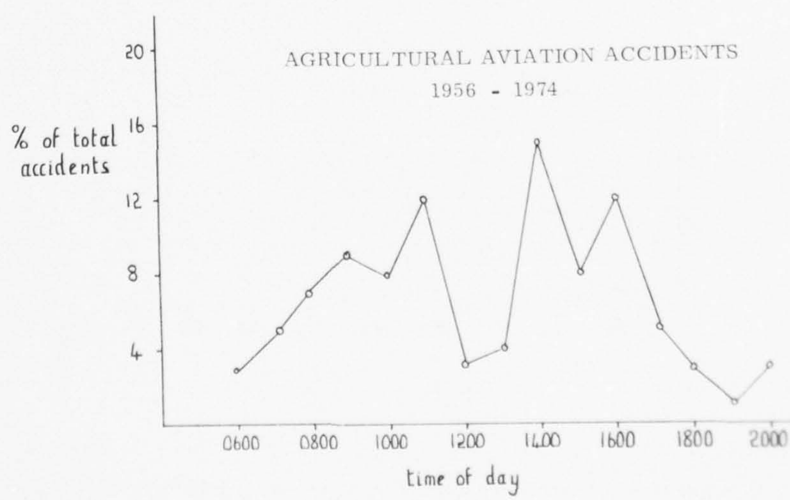

Table 3

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ing acceleration of 640 g. The threshold for fractures and more severe cerebral damage was in the

PROBABLE CAUSES OF ACCIDENTS

Investigation by the Accident Investigation Branch of the Department of Trade or by the Civil Aviation Authority of an accident usually provides an answer as to what or who was at fault. In the agricultural accidents investigated, the majority (74%) of accidents resulted from pilot error. A break down of the cause of 113 agricultural accidents in the U.K. over a period 1950 to 1974 is shown in Table 4.

AGRICULTURAL AVIATION ACCIDENTS IN U.K.

1950 - 1974

PROBABLE CAUSES	%
PILOT ERROR	
HIT GROUND WHILST SPRAYING	19
HIT CABLES	8
HIT OBSTACLES-NOT CABLES	19
POOR AIRMANSHIP	5
TAKE OFF	14
LANDING	6
MECHANICAL FAILURE	3
NON-PILOT ERROR	
WEATHER	3
MECHANICAL	16
OTHERS	4
UNKNOWN	3

Table 4

COLLISION WITH OBJECTS

This type of accident accounted for 46% of all those investigated. The main causes were collision with the ground or ground objects such as trees, with only 8% being attributed to collision with cables. The fields are usually surrounded by low hedges or high trees and thus a detailed survey is necessary before a spraying run is undertaken. The prevailing wind might make flying difficult and in such cramped conditions the pilot may take undue risks. The solution rests in good pre-flight planning with more emphasis on safety. The ground strikes are sometimes caused by hitting wild oats which grow above the wheat being treated or by diversion from the preflight plan.

POOR AIRMANSHIP

The poor airmanship shown by pilots consisted of inadvertant stall turns and these involved pilots with considerable experience. Such experience could lead to over confidence and this is the most likely cause of the pilot error.

TAKE OFF AND LANDING

A high percentage (20%) of accidents occured where the aircraft failed to take off or ran out of landing space. Overloading was the cause on many occasions and even after dumping the load several aircraft still did not manage to gain sufficient airspeed to make a normal take off.

A normal cycle of events consisting of take off, spray run, landing, refuelling and take off takes about ten minutes. The average time of flight during this cycle is approximately three minutes.

AIRCRAFT MALFUNCTION

Engine and airframe malfunctions were mainly caused by poor maintenance of the aircraft by ground staff. Lack of proper ground servicing facilities and inadequate inspection of the airframe were the main faults.

OTHER CAUSES

Other causes of agricultural accidents have been engine malfunction caused by fuel starvation. It is the responsibility of the pilot to see he has sufficient fuel on board before a run and it is the duty of the ground staff to make sure the fuel is uncontaminated.

The sudden onset of rain has caused a few accidents and many of the take off accidents might have been due to a rise in air temperature coupled with an excessive gross weight.

Bird strikes have caused several accidents and these are almost unavoidable considering the terrain in which the pilot operates.

The accident reports have not considered the physiological effects of the chemicals being sprayed. In fatal or gross spillage accidents thought has been given to the presence of acute poisoning but this has been directed towards the immediate cause of death rather than a chronic exposure.

The age of the pilot does not always correlate with experience and whilst most accidents occured in the 21-30 year age group many of these pilots had flown for several thousand hours. It may be true that many young pilots take up crop spraying solely to gain experience and increase their flying time. Table 5.

AGRICULTURAL AVIATION ACCIDENTS IN U.K.

1960 - 1974

Pilot Age Groups

	Number	%
Under 21 yrs	1	1
21 - 30 yrs	44	54
31 - 45 yrs	24	30
46 - 60 yrs	12	15

Table 5

The statistics show a greater tendency for crashes to occur with inexperience on the aircraft type but the pilots with most total flying time were more likely to be involved in an accident. Table 6.

Statistics may be interpreted in many ways. It may be argued that an agricultural pilot is going to be involved in an incident at some stage in his career and the more hours he logs the more likely this is. The inexperienced aviator is at greater risk but he also takes less chances and tends to fly by instruction rather than by experience.

There is no direct supervision of flying standards of agricultural aviators at present in the United Kingdom. The introduction of a two seater training aircraft for this purpose along with an appropriate agricultural and chemical licence rating would improve safety for all concerned.

AGRICULTURAL AVIATION ACCIDENTS IN U.K.

1960 - 1974

% Hours flown by pilots involved in crashes

	On Type	Total
Less than 250 hours	45	4
250 - 1000 hours	37	26
1000 - 5000 hours	18	48
Over 5000 hours		22

Table 6

TOXIC CHEMICALS

Effects of the organophosphorus and chlorinated hydrocarbons are well documented and the cholinergic effect is frequently quoted. However, little is known of the chronic effects of cholinergic chemicals with small dose rates on the motor functions of a pilot.

Miosis is known to occur occasionally and such an effect might seriously hinder the proficiency of the pilot, as would the preliminary symptoms of toxicity such as anorexia, nausea and mental confusion. The work involved in agricultural flying is such that physical or mental deterioration in the pilot must have a serious effect on his flying ability. It is unlike many sedentary professions where a person may work contentedly, if inefficiently, the morning after a hard night. The pilot must have his reaction and visual discrimination at peak efficiency to ensure survival in his profession.

Ground markers are frequently exposed to toxic chemicals and more attention must be paid to this risk. The correct protective clothing, including a respirator, is seldom worn and if the weather is hot it is less likely that adequate protective measures are taken; this also applies to pilots.

It is often impossible for the markers to stand the recommended distance away from the fields and they may be inadvertantly exposed to the atomized pesticides. It is compulsory to provide wash down facilities at the sites where toxic chemicals are used but these are seldom used other than after a gross spillage.

The serial estimation of cholinesterase levels is not a sufficiently sensitive parameter for use as an indicator of pesticide exposure. The normal range for this enzyme is very wide and a drop of 50% activity is the level recommended for an enforced rest period. The instability of enzyme systems and the wide variation in normal values indicate a necessity to measure the levels of pesticides directly rather than their effect.

Few accidents mentioned the pesticide hazard in relation to accident cause and only one fatality has been attributed directly to parathion exposure.

There are no regulations at present for the medical surveillance of agricultural aviators or ground staff other than the 6 monthly medical for pilots. I think most operators would approve of closer medical surveillance. Commercial interests should be concerned with safety and legislation governing this kind of work would help.

The Australian Civil Aviation Authority has recommended cholinesterase estimation every 3 weeks, or more often if necessary, on all staff dealing with cholinergic chemicals.

It should be normal practise for the flight safety report filled in after an accident to include an indication of which pesticides had been used within the last 30, days.

AIRCRAFT DESIGN

In early days of crop spraying the converted Tiger Moth was the most commonly used aircraft, with the Piper series taking over in the mid '60s. The development of specialised aircraft such as the Piper Pawnee has improved the safety of this pilot. This aircraft has been designed to give added protection around the cockpit area but it still allows spillage of liquid pesticide into the cockpit and has no filter system on the air intake above the pilots head.

The helicopter could be described as the perfect airplane for crop spraying because of its great manouverability, but their accident rate is increasing. The main cause of the accidents has been striking the ground or a ground object, which is more common with rotary winged aircraft than fixed wing. The lower forward speeds available to the helicopter should provide a wider margin of safety, but this does not appear to be the case. A summary of aircraft involved in accidents is given in Table 7.

AGRICULTURAL AVIATION ACCIDENTS IN U.K. 1956 - 1974

FIXED WING		HELICOPTER	
Tiger Moth	35	Hiller	15
Piper	26	Bell	12
Auster	9	Westland	2
Chipmunk	3	Lama	1
Cessna	2	Djinn	1
Prospector	2	Enstrom	1
Callair	1		
Jackeroo	1		
Champion	1		

Table 7

The narrow perspex canopy found in many aircraft had proved to be a potential reason for pilots not wearing a helmet. The restricted movement and the continual contact with the side has encouraged redesign of the canopy to make it much wider.

The position of the petrol tank has been a controversial topic and the present trend is towards putting the tanks in the wings. This will lessen the fire hazard to the pilot after an accident.

CONCLUSION

The final analysis of the cause of a non-fatal aircraft accident rarely considers medical evidence and the contributory factors are seldom examined. The safety of the pilot largely depends on his own physical and mental condition and whilst many pilots learn to recognise symptoms to exposure to cholinergic agents it is too late by this stage.

The human being is insensitive to the biochemical changes that occur in the body until a substantial change has occured. It is incumbent upon the authorities controlling the licencing of the agricultural pilot to insist on continuous medical surveillance and for the laboratory to devise a sensitive biochemical indicator of depression in CNS activity.

The ground operators and the field markers as well as the pilot should be fully educated on the care, handling and toxicity of the chemicals they use. The markers would appear to be the obvious target for continued surveillance because of their high exposure and the low requirements for employment. It may be necessary to punish staff for not complying with the rules of conduct recommended by the authorities for the safe handling of the chemicals, and financial rewards for accident prevention.

The incorporation of a filter in the cockpit air intake could effectively remove one source of contamination with toxic chemical and the manufacture of protective clothing made from cool material would encourage the pilot to wear some, even in hot climatic conditions.

I wish to thank the Director General of Royal Air Force Medical Services, for permission to publish this paper.

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DISCUSSION

MACLAREN: With reference to your comments regarding safety and legal requirements for pilots and ground markers, are there not, in fact, regulations and Codes of Practice in the United Kingdom covering the handling of organophosphates and other toxic pesticides? And, while these have not been rigorously pursued in the past, has not the advent of the Health and Safety at Work legislation provided adequate safety and legal requirements independent of CAA requirements for commercial pilot licensing?

WOOTON: The Civil Aviation Authority issues a document containing both regulations and recommendations. There are no regulations to insist on medical surveillance of pilots and ground staff for short intervals. The Health and Safety at Work Act will, I hope, help achieve this objective.

WARD: Do you have any evidence that pilots are taking prophylactic medication?

WOOTON: No.

WARD: Do any of your military pilots "moonlight," that is, fly on off-duty periods, as crop sprayers?

WOOTON: The records show that in 1966 a pilot with the rank of Wing Commander had a fatal accident whilst crop spraying. He had been involved in several previous notifiable accidents. I do not know whether he was on active service or used the rank as a courtesy title.

WARD: Is this allowed by your regulations?

WOOTON: It is against service regulations for a pilot to take "moonlight" civilian occupation. I do not think a service pilot would risk his career by doing this.

BRENNAN: At the light levels likely in crop spraying, it is considered unlikely that the induced miosis and consequent reduction in retinal illumination would be significant.

WOOTON: I will accept your professional opinion for normal daylight flying, but there must be some risk for pilots who are flying during late evening and during the night, as they do in the United States. It would also depend on the level of exposure.

McMEEKIN: What instruction is given to your agricultural pilots regarding toxic hazards?

WOOTON: There is no formal educational program for agricultural pilots, but the commercial owners institute a local training scheme on the toxic hazards involved.

McMEEKIN: How much agricultural flying is done after sunset?

WOOTON: The difficult terrain encountered in the United Kingdom and the law would preclude any attempt at agricultural flying at night.

McMEEKIN: What is your determination of "type" in TABLE 6?

WOOTON: The "type" referred to is the type of aircraft rather than the type of agricultural work in volume.

ACCIDENT RECONSTRUCTION FROM ANALYSIS OF INJURIES

by

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SUMMARY

Careful analysis of known dynamics of impact in fatal aircraft accidents has led to an enhanced understanding of the pathogenesis of the injuries incurred. From an ongoing study of over 500 fatally injured crewmembers of U. S. military aircraft every year and an analytically oriented research program in which injury patterns are verified by computerized simulation techniques, it has been possible to prepare estimates of injury correlated with both the magnitude and the direction of the applied decelerative forces.

Conversely, when an accurate tabulation of postmortem injuries is correlated with measurements of the path of the aircraft after it strikes the ground, the dynamics of impact may be deduced. This process is invaluable for accidents that occurred without witnesses or survivors and in which crash damage to flight instruments or the absence of flight-data recorders makes calculation of impact kinematics difficult.

Skeletal injuries, particularly vertebral compression fractures, lacerations and contusions of viscera, aortic tears and lacerations, and cutaneous contusions caused by compression of harnesses and seat belts, are important factors in determining the direction and magnitude of the deceleration vector.

INTRODUCTION

Aviation pathology has great potential value in the clarification of those events that precede, occur during, and follow an aircraft accident. The tissues of the human body, with their plasticity and diversity, can serve as positive documentation of both the magnitude and direction of the forces generated, of the presence of toxic hazards before the accident and of the occurrence of fire and structural fragmentation in the postcrash period (1-3).

In the past, emphasis has been put upon a detailed structural analysis of the airframe and engines in order to determine the dynamics of an airplane accident. There are at least two reasons for this. In the process of development and construction of airframes a great deal has been learned concerning the static and dynamic properties of the various components of the aircraft. This information can be combined with an analysis of the wreckage in an attempt to reconstruct the accident.

More important has been the tendency of the pathologist investigating an aircraft accident to confine himself to the simple determination of cause of death and identification of the deceased. This has stemmed in part from the outgrowth of aviation pathology from civilian forensic pathology and in part from the impression on the part of both physicians and engineers that there is little else of value for the aviation pathologist to offer.

In recent years, the design of ejection seats, of active and passive restraint systems, and of generally improved airframe crashworthiness has led to an explosion of information on the static and, to a lesser extent, the dynamic properties of various human tissues as influenced by a variety of forces. Pioneers in the dissemination of this information have been the organizers of the annual Stapp Car Crash Conference and the Federal Aviation Administration, which has put out various publications on it. There has also been an increase in the number of trained forensic pathologists with an interest and background in aviation as well as an ability to talk to and work with the technical members of a board investigating an aircraft accident. The result of these changes has been an enhanced ability of the aviation pathologist to use the information he obtains from postmortem anatomic and toxicologic studies not only to determine the cause and manner of death but also to assist the investigation board in determining the cause and manner of the accident.

PLAN OF SUGGESTED PROCEDURE

One of the earliest important uses of medical information in clarifying the physical circumstances of an accident was in the now-famous series of Comet disasters, which occurred over 20 years ago (4, 5). These accidents demonstrate the importance of the aviation pathologist's or flight surgeon's possessing a sound method for collecting and interpreting this information. What we will emphasize in this paper is such a technique. We will then present both our experience and the information found in a review of the literature about the magnitude of forces sufficient to produce the most common injuries seen in personnel who have been injured or killed in aircraft accidents.

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*The opinions or assertions contained herein are the private views of the authors and are not be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

Before starting out, it is always helpful to obtain a preliminary impression of the operational circumstances of the accident. There is little value in doing a "blind" autopsy. In forensic pathology it is dangerous, and in aviation pathology it is next to worthless. There is usually some indication as to the cause or at least the general circumstances surrounding an accident. Bad weather with turbulence might indicate an in-flight structural failure or loss of a rotor blade. Approach accidents may be associated with wind shear. In a tactical training environment, helicoptor accidents are associated with misjudged "pop-ups" or NOE (nap of the earth) flight maneuvers.

The best way to obtain such a preliminary evaluation is by conducting a personal inspection of the wreckage. Frequently those details that are most useful to the aviation pathologist in understanding the various fatal injuries are thought to be unimportant by the structural analysts. If the injuries are predominantly right sided in the occupants of a helicopter that has impacted on its right side, the presence of a single severe crush injury to the leftside of a victim might prompt a search for some other mode of structural failure. It is often of great value to visit an intact model of the involved aircraft. The location and type of controls, the colored markers on instrument dials, the location and configuration of rudder pedals, and the type and location of occupant restraints will give the pathologist a much greater degree of confidence in his opinions about the production of various injuries. Unfortunately, the logistic requirements and restricted time under which the aviation pathologist often operated may limit the accessibility of the scene of the accident to him. Similarly, it is unusual for him to be present when the bodies are removed from the wreckage.

The actual postmortem examination must be thorough, searching, and unhurried (6, 7). It is of primary importance not only to catalogue all of the injuries but also to arrange them into meaningful groups and patterns. The best aid for this is the use of diagrams so that a multiplicity of injuries can be seen at a glance. When all of the external and internal injuries have been tabulated, they should be grouped into injuries that are produced by deceleration as opposed to those produced by impact or other mechanisms. The recognition of these acute impact injuries (8) as opposed to those injuries produced by deceleration may prove difficult, and it is well to remember that decelerative forces are always transmitted to the body via some restraining mechanism (harnesses, seat backs, hardpans) and that, if severe enough, these may mimic impact. Trauma to the body from impact shares some of the features of deceleration injuries (particularly in the case of falls from heights), but careful examination of the injury, in conjunction with study of the circumstances, will assist in their differentiation. Impact-type trauma is often associated with tracts leading inward; decelerative injuries are often associated with injuries that begin within the interior of the body. With the increased protection being afforded to the head by means of helmets, restraints, air bags and energy-absorbing panels, visceral integrity and fractures of the cervical spine represent the limiting factors in many crash situations.

X-ray films are of great importance in understanding the dynamics of an aircraft accident. Bearing in mind that the interiors of the skull, thorax, abdomen, and pelvis will be viewed in the course of the autopsy, the aviation pathologist will optimize limited resources by concentrating his attention on procuring roentgenograms of hands, feet, proximal extremities, and the spine. "Scout" films may be shot through a body bag before attention is focused upon a particular detail. This helps to reduce contamination and excessive soiling of radiographic facilities, which are usually used for living patients.

After the injuries have been divided into impact vs. decelerative types and these further subdivided by type and location of injury, it is important to determine the magnitude and direction of the forces necessary to produce them. This subject is later treated in detail.

It is useful to search out an injury or pattern of injury that does not fit in with the others present on the body of the deceased. Even more useful is the discovery of an unusual pattern among the patterns found on the many victims of the same accident. This "odd man out" theory was first proposed by Mason (9) in investigating the fatalities resulting from a bomb explosion aboard an air carrier transport. It also has significance for the investigation of military aircraft accidents.

A U. S. Army helicopter collided on its left side with a rocky hillside. Those crewmembers seated on the left side of the aircraft suffered severe crushing injuries on their left sides. The aircraft commander, in the front left seat, also had a hatchet-like avulsion of the posterior portion of the right temporal and occipital portions of his skull. This was later shown to be the result of a strike by a main rotor blade that was separated by mast bumping during severe turbulence in flight.

When the collection of medical data is complete, the calculation of the magnitude and direction of forces made, and the preliminary details about the technical circumstances of the accident obtained, a theory should be formulated that will be as compatible with as many of these features as is possible. Then it is necessary to determine whether this theory is compatible with any new information that has been uncovered in the progress of the investigation. It will often be necessary to revisit the wreckage or scene of the accident if there appears to be a conflict between the medical evidence and the initial impressions of the engineering analysis. The medical evidence may need reinterpretation, or the damage to the aircraft may have to be viewed in a different light.

It is to be hoped that next there will be a gradual refinement of these two aspects until a common working theory has been proposed. The primary contribution that the aviation pathologist can make to the understanding of an accident is an interpretation of the dynamics and sequence of events in an accident that has been independently reached. When both medical and engineering hypotheses are similar they reinforce each other, and when different they focus attention on details that otherwise may have been misinterpreted or overlooked.

CALCULATION OF DECELERATION FORCES

When an impulse is applied to a structure, the energy of impact is distributed throughout that structure in a manner that is dependent upon (a) the magnitude of the impact, (b) the duration of its

application, (c) the area over which the force is applied, (d) the immediate underlying physical characteristics of the structure and the impacting body, and (e) the availability of pathways for conducting this energy away and dissipating or redistributing it in the surrounding tissues.

The energy of impact is a function of mass, velocity, acceleration, and time. These relationships may be summarized in Equation 1:

$$\text{Eq-1.} \qquad E = \frac{MV^2}{2} = \frac{FV^2}{2A} = \frac{FAT^2}{2}$$

where E is the energy of impact, M the mass, V the net change in velocity occurring during the deceleration, and T the duration of the impulse. The force of impact, F, is defined as:

$$\text{Eq-2.} \qquad F = MA,$$

the product of mass and acceleration. At 1 g the condition of rest, mass may be continually added to a structure at a point of application until it deforms to a predetermined extent or until it suffers structural failure. Such a static condition does not closely correspond to the dynamic conditions that occur in accident trauma, where the forces are applied over short periods of time on the order of milliseconds. It is obvious that under static conditions there has been a maximal opportunity for the load to be distributed throughout the structure being stressed (10).

In all of the tissues of the body, the duration of the impulse has a dominating effect upon the type of injury seen. For impulses that last on the order of 500 msec. or longer, injuries are produced by (a) the direct action of restraint systems and (b) the differential movement of various body organs. Fractures of the clavicles and ribs, abdominal contusions, pancreatic hemorrhage (11), and perhaps capsular tears of the liver and spleen are examples of the first mechanism. Intimal tears of the aorta, tears of the renal arteries, and anterior cardiac contusions are examples of the latter. These are due essentially to displacement in the horizontal plane, since vertical changes of velocity are usually accomplished in much shorter periods of time and within shorter distances.

Between 25 and 500 msec., the duration of most crash pulses, injuries due to both horizontal and vertical decelerations are seen. Injuries present during this time frame are due to decelerative forces acting on the body applied by restraint systems, impact against cabin structures and/or the ground, and the effect of failure of restraint systems. Following such a failure, injuries are produced that are caused by the mechanism of failure itself, impact against cabin structure while partially restrained, and complex patterns of injuries as the occupant and aircraft rapidly come to a halt in random and unpredictable attitudes. Because of this unpredictability, it is very difficult to use injuries produced after restraint failure in the calculation of force vectors unless the time intervals are so short that one may be reasonably sure that no significant movement occurred. Severe tears and disruption of the viscera, multiple comminuted fractures of the extremities, compression fractions of the vertebrae, and evisceration and avulsion of internal organs are seen in this range of injuries.

Provided that the total energy that must be dissipated is small enough, the rate of onset of acceleration is not important, but even at a slow walk a 150-lb. man possesses the 600 to 800 ft-lb of energy necessary to fracture the nasal bones and at 10 miles per hour there is enough kinetic energy present, if concentrated over a single area, to result in severe injury or death.

Impulses of extremely short duration produce injuries that are quite different from the two preceding types. These would be rates of onset in excess of 50,000 g/sec. and lasting less than 10 msec. In this instance the impulse is over and the kinetic energy absorbed before the individual components of the body have time to respond. The high natural frequency of these short-duration impulses are so much greater than the natural frequency of the body or of individual organs that the energy is absorbed and then released diffusely. If great enough, the effect of this diffusely absorbed energy is widespread disruption of structure. It is best seen in high-speed jet aircraft accidents in which that portion of the aircraft in front of the occupant has been completely obliterated and the individual strikes the ground with a velocity very little changed from his initial speed.

Such "impulsive" impacts may be recognized pathologically by the presence of extensive shards of skin, often representing the entire integument of the thorax or abdomen, split down the front or back and devoid of the viscera and skeleton it once contained. Calculated g forces for such impacts are of the order of 600 to 1,000 or greater and represent energy levels of 1 to 3x106 ft-lb. This is the situation of a 150-lb. man traveling at about 200 ft/sec. and assuming a stopping distance of only 1 foot. At the upper part of this range, complete and uniform destruction of the entire body becomes the rule, although it is rare not to discover at least a few fragments.

The mass term of Eq-1 and Eq-2 refers to the mass of the occupant (or portion of the occupant) and not the mass of the vehicle. There are structures that effectively add to the mass, however, and thus to the energy of impact the life-support equipment of the occupant must absorb. This is primarily the mass of the seat back and that of the restraint system itself. These formulas may also apply to any individual part of the body that may move quasi-independently of the rest of the body. This primarily applies to the head and extremities, organs that pivot at only one end. For other body segments, energy is not only being absorbed by the segment being stressed but may be transmitted and absorbed by adjoining body segments. This depends upon the duration of the impulse and the orientation of it as applied to the segment in question.

Because of its large mass the vehicle in a severe accident contains an energy for dissipation that is vastly greater than that contained in the bodies of the occupants. It is the goal of good crashworthy design that this energy be dissipated in controlled deformation of the structure, maintenance of a habitable cabin volume, and a pattern of breakup that allows a decrease in mass without endangering the occupants. At all costs this kinetic energy should not be transmitted to the occupants or to their seats by overly rigid structure.

The area over which the force is applied has its most obvious application in the advocacy of rearward-facing aircraft seats. With this arrangement the forces are distributed over the entire area of the back of the person. The width of the webbing in restraint harnesses will insure that the decelerative forces that are applied to the thorax are not concentrated over individual ribs, which would cause fractures and cardiac lacerations. This demonstrates the need for the aviation pathologist to be familiar with the restraint system in use when he is interpreting a particular injury.

The type of tissue at the point of impact and the composition of the impacting material are important in attenuation of crash force. There may be an initial opportunity for considerable absorption of energy before transmission to vital organs. The types of tissue most efficient in this respect are the large muscular and fatty masses of the abdomen and buttock and fascial planes such as that of the tensor fascia lata. Compression of these tissues may increase the effective stopping distance and significantly diminish peak g forces. For a similar reason there has been much recent interest in energy-absorbing structural panels (12).

Both the tissue and the impacting surface may flatten out during the impact and spread the force over a greater area.

The mechanism for initially redistributing the energy of deceleration is by transmission of this energy through bone (femoral forces transmitted to the pelvis via the acetabulum), tendons, and muscles. A demonstration of this effect is the dramatic reduction of peak g forces in the head and particularly in the neck that can be accomplished by simply tensing muscles and "opening up" pathways for force transmission and, hence, attenuation.

The direction from which an impulse originates will also determine the availability of other dissipative pathways. A force applied perpendicular to the long axis of the femur will cause more damage than one applied along its axis. In the latter circumstance part of the energy is dissipated by the transmission of an axial force to the bony pelvis and the stout muscle groups on the back and on the lateral aspects of the trunk. A knowledge of the usual seating posture of a particular crew station is important in interpreting injuries, particularly of the pelvis, trunk, and lower extremities.

It is clear, then, that when attempting to evaluate the degree of force that produced a particular injury and from this calculating the impact conditions that caused it, the aviation pathologist must search out information in the five categories mentioned.

The magnitude of the impact can be determined by careful gross examination of the tissues. X-ray films often provide a clearer impression of the degree of bony trauma than does dissection and do not reflect postmortem changes.

The duration of the impact may be ascertained from the injury in an affected part as well as from an engineering estimate of the velocity of impact, the impact attitude, and a rough estimation of stopping distance. With this information, Eq-3 gives an estimate for the average g forces in a crash:

$$\text{Eq-3.} \qquad Am = \frac{V}{2D}$$

where Am is the average deceleration (in ft.sec.-2). It is best to assume a triangular deceleration pulse, and in that case the peak g force. Ap, is equal to twice Am. Under these conditions the time (t) required to completely dissipate the velocity change V is given by

$$\text{Eq-4.} \qquad t = \frac{V}{Am}$$

The rate of onset of acceleration (J = "jerk," the third derivative of displacement with respect to time) is given by

$$\text{Eq-5.} \qquad J = \frac{(Ap)\,(t)}{2}$$

The area of the impact and its composition with respect to attenuation of injury may be ascertained by careful dissection, particularly of areas of subcutaneous tissue that border obvious contusions and lacerations, and by a thorough briefing of the types of life-support equipment present and their apparent utilization. Finally, some familiarity with seating arrangements and, if available, premortem anthropometric measurements of the deceased may aid in estimating the orientation of the decelerative forces.

MODIFYING FACTORS AND IMPACT INJURIES

Factors that may modify impulses and decelerative forces should be mentioned. Shoulder harnesses and seat backs attenuate deceleration in the -Gx direction. Items of importance in this instance are (a) the degree of belt preloading, (b) the stress/strain characteristics of the webbing, (c) the amount of free travel before inertial lockup occurs, and (d) the ultimate failure limits of the belt and the belt attachments. If the occupant is facing to the rear, the seat back will attenuate an impulse in the -x direction. In this case factors of importance are (a) the nature of the padding and depth of the seat back, (b) the interactions between the back and other energy-absorbing components of the seat, and (c) the ultimate failure limits of the back.

Modification of crash impulses in the $\pm z$ direction are obtained by (a) placing padding between the seat bottom and the hardpan, (b) the stroking and other energy-attenuating properties of the supporting structures of the seat's tiedown, (c) belts in a multipoint harness system that envelop the shoulders, lower torso and thighs, and (d) by straps extending from the seats to the ceiling and lateral walls of the vehicle's cabin. Lateral $\pm y$ attenuations of impulse are created by (a) lateral components of multipoint seat harnesses and (b) surrounding cabin boundaries.

Apart from decelerative trauma, impact may be sustained by (a) impact with the ground, (b) contact with the disintegrating structure of the aircraft, (c) laceration and penetration of the head, thorax, and extremities by control sticks and instrument knobs, (d) strikes by propellers, turbine blades, and helicoptor rotors, (e) a hazardous postcrash environment in which fire, carbon monoxide, and other toxic products of combustion are present, and (f) artifactual changes in the bodies caused by the unwitting interference of rescue personnel or predators or the effects of weather or postmortem changes.

Ground impact may be recognized by a linear pattern of abrasions and the presence of dirt and debris ground into clothing and wounds. Bodies may be found still strapped into their seats, the entire seat-man assembly having been hurled out of the aircraft. When bodies are found scattered in a linear fashion under the reconstructed flight path of the aircraft, in-flight structural failure should be suspected. If a detailed seating plan is available, or if family groups can be identified, the pathologist may be able to give some clue to the precise sequence of the structural failure that occurred. If impact has occurred from an altitude sufficient for the released bodies to reach terminal velocity, extensive fractures of the skeleton will be present. These will have either a widespread distribution or, if the ground strike occurred in a particular attitude, they may be limited to a portion of the body. For example, in a rapid, partially controlled parachute descent, if the feet initially strike the ground there may be collapse of the acetabulum with the femoral heads driven into the pelvic cavity. In assessing such injuries, particular attention should be paid to the presence of any partially deployed survival equipment that may have attenuated the ground impact and to any features of the ground itself that may have significantly altered the conditions of impact.

Contact with the disintegrating structure of the aircraft can usually be recognized by the random introduction of metallic fragments into the body cavity. It is important to have someone present at the autopsy who will be able to identify this debris with reference to its original location within the aircraft. The pattern injuries produced by impact with control sticks and instrument knobs on the instrument panel have long been recognized as being of value but the presence in the depths of wounds of the colored "tapes" used as markers on the faces of instruments may also be helpful.

Propellers, rotor blades, and turbine blades produce a distinctive combination of blunt force and chopping injuries, causing avulsion of body parts. Particularly in cases of mid-air collision involving propeller-driven aircraft, the bodies should be examined for evidence of propeller strikes. The wounds should be inspected for traces of paint, fragments of anti-ice equipment, and other mechanical devices that may be associated with a particular propeller assembly.

These impact injuries of nondecelerative type, when properly recognized and catalogued, and when the various factors that may cause their production and modification are taken into account, will provide valuable information about the initial stages of the accident and the ensuing sequence of events that are not strictly related to occupant kinematics.

RESPONSE OF HUMAN TISSUES TO DECELERATION

It is impossible to extensively review the vast literature that has accrued since World War II on human response to impact. Recent reviews are those of Channing (13), Snyder (14), and AGARD (15). Much of the literature on impact injury describes various models for the understanding of the mechanism of injury production. In the following sections we shall concentrate on that literature that sets threshold levels for specific injury. It is worth noting that these levels vary widely among different authors. This variation results from (a) a lack of uniformity of experimental design, particularly with respect to the measurement of loading and the nature of the impacting surface, and (b) a wide variety of experimental subjects, such as assorted anthropormorphic dummies, cadavers, human volunteers, animals, and computer programs that simulate impact and injury.

The information that follows on injuries to various organs was collected from the literature and also represents the experience of the Aviation Pathology Division of the Armed Forces Institute of Pathology, where over 500 aircraft accident fatalities are reviewed and coded each year.

A consideration of the injuries present in the deceased and a knowledge of the various thresholds needed to produce them will furnish a range, usually clustering around a lower limit, of forces for a particular injury. It is necessary to collect a number of such ranges or lower limits in order to

narrow the estimation of force and deceleration that were applied to the body as a whole. An accident may produce a "total body" deceleration of only a few g yet be fatal because of a localized area of higher values. It is similarly important to note and tabulate what injuries did not take place, as a means of fixing upper bounds on the accident forces and decelerations.

Abdominal Viscera. Much of the literature on visceral injuries has attempted to quantify and correlate the lesions produced with the intrinsic stress/strain properties of the tissues (16). It is difficult to translate this knowledge into information about deceleration after impact. Hepatic and splenic injuries are those most commonly seen (17). Mays (18) gives an energy value of 285 to 360 ft-lb as being sufficient to cause capsular tears and bursting of the liver. If the victim is wearing only a simple lap belt, peak decelerations of 25 to 40 g are sufficient to cause hepatic injury. As the complexity of the restraint system increases and the load is distributed over a wider area, this "total body" deceleration threshold for abdominal injury increases to the neighborhood of 100 g.

Weis and Mohr (19), using x-ray cinematography, studied visceral movement in human volunteers subjected to a velocity change of 7ft./sec. over a duration of 7.5 msec. They noted a net axial movement of the liver of approximately 1-3/4 inches. In a somewhat similar study, Kazarian (20) found that a -Gx pulse of 120 g would produce hepatic capsular tears in monkeys. At the lower end of these ranges the principal tears are found at and near the suspensory ligaments and at the hilum, another relatively fixed point. The superior surface is relatively spared, no doubt because of the cushioning effect of the diaphragm.

At levels of 150 g and higher, bursting and disruption of the hepatic parenchyma are seen. Since the capsule of the liver constitutes its major source of strength, it is probable that disintegration proceeds rather rapidly once it is broached.

Comparable values for the spleen, the second most commonly injured abdominal organ, have not been published. Pancreatic injury from seat-belt compression has been reported (21). The bowel can have a number of injuries. At lower levels, 25 g we begin to see contusion at the roots of the mesentery. Contusions from seat-belt compression are not uncommon, but evisceration and loss of integrity of the anterior abdominal wall usually occurs before there is "flailing" of loops of bowel and loss of continuity. This probably occurs at levels higher than 150 g. In applying any of these considerations to abdominal trauma, care should be taken that the injuries were not produced by other mechanisms such as fracture of the ribs or by penetration of the abdomen by portions of the aircraft during structural breakup.

Thoracic Viscera. The injuries most commonly seen in this site are those of the lungs, heart, and great vessels. The same mechanism that causes hepatic and splenic injuries applies to the lungs. Subpleural hemorrhages, similar to hepatic capsular tears, are seen at about the same level of deceleration. Because of the increased elastic tissue component of the lung there is less of a tendency for complete disruption. Amputation about the hilum is frequently noted following high-speed impacts of greater than 200 g .

Injuries to the heart may be caused by laceration by broken ribs, forceful thoracic compression, or by bursting from increased intraluminal pressure (21, 22). Although static values of the stress/strain characteristics of the myocardium are available in the literature (23), the dynamic properties have been less extensively studied. Epicardial contusions caused by direct compression can be produced at a rather low level of applied force if the sternum is depressed sufficiently. They are a not uncommon sequella of manual compression during cardio-pulmonary resuscitation. If an adequate restraint system is present, the amount of energy needed to produce this injury is of the order of 3,500 ft-lb applied over 20 to 30 msec.

The mechanical properties of the aorta vary widely with age (23) and with pre-existing disease. Intimal tears caused by violent motion of the heart about relatively fixed attachments are usually transverse in shape, indicating a mechanical rather than a hydraulic origin (24, 25). Given an adequately restrained thorax, such tears are first noted at levels of deceleration approaching 40 to 60 g and proceed to through-and-tears when the values reach a range of 60 to 80 g. These particular injuries probably represent the limiting factor in survival at the present time.

Injuries to the tracheobronchial tree are frequently seen, but their mechanism of causation is obscure. Tears are often seen at the point of bifurcation and are more common on the left than on the right (26), possibly because the mass of the heart and ligamentous attachments of the great vessels limits movement. It is not possible to correlate injuries with levels of deceleration from the information in the literature.

Because of their extensive dependence upon the type of restraint system used, their variability in threshold, and the lack of known dynamic properties of behavior under impact, visceral injuries are not the most useful for estimations of crash forces. A major disadvantage lies in the fact that the entire visceral mass is of relatively homogeneous composition, and therefore the direction of applied force is not an important factor in the production of an injury here than in other regions of the body. Since the production of capsular tears in the liver, lungs, and spleen may have their origin in the interactions of propagated pressure waves in the thorax and abdomen, the location of such tears may be independent of the direction of the driving force.

Spine. The injuries seen in the spine vary, depending upon the direction of the impacting force. With purely vertical stresses there is an initial slight twisting movement as the individual vertebrae compress the intranuclear discs and rotate about each other (27). The articular facets engage each other, and this is followed by loading of the intra-spinous ligaments and muscles. Natural regions of weakness in the bony column are C6-7 and T12-L1, where there is a meeting of the reverse curvatures. The facets are quite strong, and failure usually starts at the vertical end plates of the vertebral bodies (28) on the anterior or posterior lip. At an impulse of 20 g collapse of an entire vertebral body may be seen. At values higher than this, disruption of the ligamentous framework of the spine occurs, and at peaks of over 150 to 200 g there may be loss of continuity of the spine and overriding of the fragments. An injury usually accompanying this is transection of the aorta at the same level.

As the axis of application of force changes from the -Gz to the +Gx direction, increased force is applied to the transverse ligaments and facets. There is usually an increased stopping distance in the horizontal plane, however, and other components of the axial skeleton take up the load. Horizontal impulses of greater than 100 to 150 g are necessary to produce severe injury to the lower portions of the spinal column.

The Chance fracture (29), which involves the posterior vertebral arch, the laminae, pedicles, and transverse and spinal processes, is due to extreme flexure of the upper body, as may occur during failure of upper-torso restraints (30). This may be difficult to detect radiologically but can usually be demonstrated by careful dissection and, if necessary, clearing of the specimen. This fracture and minute collapse at the anterior lip of the vertebral body may be among the first lesions seen in the spine.

Begeman et al. (31) studied the loads resulting from g deceleration in the spine. Using cadavers, their test runs on sleds produced g forces ranging from 12 to 16. The loads generated varied from 450 to 1,250 lb. Fractures of the crushing variety were found at L1, T9, or T7 in all of the test subjects. This probably represents a lower limit for the onset of injury. The total duration of these pulses was on the order of 170 msec.

Factors modifying spinal injury include the orientation of the spine at impact, the type of restraints and seat cushions in use, and the presence of pre-existing spinal injury or weakness. Since the total stopping distance in the vertical direction is quite small, minor errors in the approximation of this value will affect the calculated g forces significantly. The wreckage can be examined for vertical deformation and the depth of the gouge in the earth measured. It is important to correct for the slope of the terrain, since this can exert a dominating effect on the final calculation of stopping distance and hence of vertical velocity.

Kazarian et al. (32) have presented a detailed analysis of fracture patterns in the spines of both man and rhesus monkeys resulting from +Gz loading. They found that for "impulsive"-type loading (2 msec.) at 800 g, there was severe comminution of one or two vertebrae, whereas with increased duration (16 msec) and lower loads (150 g) there were only compression fractures of vertebrae, and these spread out over a greater extent. They also determined that the region of greatest probability of fracture was in areas of reverse curvature, and they attributed this to a change in bearing of the articular facets.

Even more important, they warned of the inadequacy of routine x-ray examination in detecting early injury patterns. This has been our experience as well. The earliest signs of failure of the spine are hairline fractures of the articular facets, chance fractures of the neural arch and disruption of the nucleus pulposus. These may be seen with decelerations of as little as 6 to 10 g when the rates of onset are in excess of 1,000 g/sec.

Extremities. Impact studies have defined the tolerance levels for the human femur (33, 34). Between 25 and 50 g there is little or no damage when the impact is perpendicular to the shaft. This experimental situation produces energy levels of 200 to 400 ft-lb, and the duration of the pulses were from 10 to 25 msec. As the duration of the pulse decreased (33), there was increasing damage to the superficial tissue of the leg. The use of embalmed cadavers in many of these studies, however, makes soft tissue injuries difficult to interpret. Between 35 and 75 g, hairline fractures of the shaft of the femur were produced as well as severe comminuted fractures of the patella. At these energy levels (400 to 600 ft-lb) pulses of short duration produced severe shattering injuries of the patella; at longer durations there were destabilizing fractures of the tibial shelf and the inferior condyles of the femur.

With levels of absorbed energy in excess of 600 ft-lb, corresponding to applied forces of 2,000 lb extending over a period of 10 to 20 msec., there were severely comminuted fractures of the femur. These correspond to mean accelerations of 75 g or greater. Cooke and Nagel (34) maintained the force applied and the energy absorbed essentially constant and varied the duration of the applied pulse. Stress "waves" were observed passing up the length of the femur at the longer durations, and strain gauges revealed considerable afterloading related to the resolution of the bending stresses that had been induced in the bone by the initial deflection.

King et al. (35) studied the response of the femur and patella to forces of varying duration and magnitude. They concluded that approximately 1,700 ft-lb for 50 msec. was a conservative estimate of the energy that could be applied to the human femur before fracture. They also concurred that at very short durations- 3msec.-patellar fractures were by far the more important injury and that impulses of this duration would have to be in excess of 2,700 ft-lb before femoral fracture would occur. The actual initial point of fracture--pelvis, femur, or patella--was more dependent upon duration of pulse and degree of muscular and fascial tensing than upon any wide differences in ultimate intrinsic strength.

Once a severe comminuted fracture of the femur occurs, it is probable that this fracture rapidly proceeds to amputation. At the moment of fracture there is a marked plateauing of g forces on the tissue below the break. The considerable energy stored in bending deformation is released to the surrounding tissue by the jagged ends of the bone with ensuing laceration. In addition, the energy of deceleration that had been being previously loaded into the bone is now fully applied to the soft tissues. The skin provides considerable reserves of strength because of its highly elastic composition. It is not uncommon to find cases in which the bone and muscle are entirely disassociated at the point of fracture but the limb remains attached to the body by a partial flap of skin.

Patellar injuries are seen at g levels of 30 to 50 when the onset of these forces exceeds 2,000 to 3,000 g/sec. Even at lower levels, ligamentous tears can cause severe destabilization of the joint, which can prevent egress from an aircraft. The failure pattern of the anterior cruciate ligament of the knee was studied by Noyes et al (36). Significant variation of behavior was noted to be a function of rate of onset of stress and orientation of the stress in relation to the osseous attachments of the ligaments. Three patterns of falure were observed: (a) ligamentous failure, (b) tibial avulsion fracture through the bone underlying the insertion of the ligament, and (c) cleavage of the ligament-bone interface. The load levels for these failures was approximately 225 lb.

Kramer et al. (37) studied the fracture characteristics of the human tibia. Fifty percent of the population studied could be expected to incur tibial fractures when a force of approximately 1,000 ft-lb was applied, corresponding to a deceleration of only 15 to 20 g. Higher levels of tolerance and failure could be expected to exist in a younger military population.

Similar studies are not available for the human arm. From scaling considerations, the same range of figures as seen for the tibia should apply to the humerus, and lower values should apply for the forearm. An additional mode of humeral failure is avulsion through the glenoid fossa caused by violent flailing about the shoulder. The energy level needed to produce an injury of this type seems to be quite high, probably in excess of that needed for fractures of the lower extremities. In the leg it is more common to see amputation through the anatomical neck of the femur than disarticulation. The seated posture may explain this.

Careful examination of the small bones of the hand and feet may give information as to the identity of the pilot at the time of the accident, but the more usual case is for many of the fatalities to have similar fractures. Comparison of these many fractures may be made so as to see whether a single person has an unusual distribution or pattern that may identify the pilot.

Modifying features in extremity injuries are the presence of restraints (as part of the ejection seats), seat posture, and angle of incidence at impact. In particular, off-center forces applied to the upper leg, which produce a rotary motion, are productive of much less injury than direct impact (33), presumably because of the sharing of the load by the ligamentous attachments of the leg and because of the ability of the femur to store considerable amounts of energy in twisting. Flexing of the knee has a similar protective effect.

Head and Neck. It is useful to consider two levels of injury threshold in head trauma: cases with skull fractures and those without. Swearingen (38) studied the fracture thresholds of the various parts of the skull and found that the impacting surface was of the order of 2 to 4 in.$^{+2}$, nasal bones were fractured at 30 g, the frontal eminence of the mandible at 40 g the zygoma at 50 g, the frontal bone at 80 g, and the area of the mandible and maxilla in the region of the front teeth at 100. If the force was applied over 8 to 10 in.$^{+2}$, the frontal bone could survive over 200 g without fracture, and if the entire face was used as a decelerative surface the tolerance was over 300 g.

Gurdjian (39) determined that energy levels as low as 35 to 70 ft-lb are sufficient to produce single hairline fractures of the skull. Numerous studies, summarized by Snyder, give the range of loads for frontal and parietal fractures as 1,000 to 1,700 ft-lb (averaging about 1,200) for frontal bone and 770 to 1,290 (clustering about 850) for parietal bone. The minimal value at which failure occurred was about two-thirds of the mean for the respective types.

Provided, then, that fractures and deformations of the skull are not allowed to take place, the head is remarkably resistant to injury. In a follow-up study, Swearingen (40) reported both experimental and accident-investigation data showing that peak accelerations in excess of 400 g with rates of onset in excess of 105,000 g/sec are survivable provided that the motion is purely translational. Higgens et al. (41) offered a similar result with angular accelerations in excess of 1.5×10^5, which translate to a linear acceleration of about 600 g.

The large amount of literature on the mechanism of production of intracranial trauma gives a few clues as to the relation between the trauma and the causal mechanism. In the absence of fracture with underlying contusion and laceration of brain tissue, the anatomic evidence of injury consists of subarachnoid bruises and small tears of bridging vessels. Omaya (42) summarized various models of impact trauma to the brain and head, reviewed much of the literature pertinent to this problem, and offered a 50 percent probability of concussion in man when the angular acceleration exceeded 1.1×10^3 radians/sec.$^{-2}$.

Shatsky (43) employed rhesus monkeys and found no parietal fractures at forces up to 390 ft-lb and accelerations in the g direction of over 470 g, but neurologic injuries associated with intracranial contusions and subarachnoid hemorrhage were common in this group. With forces in excess of 500 lb and decelerations in excess of 500 g fractures, first hairline and then depressed, became progressively more severe and were associated with more severe intracranial injury. For occipital impacts the threshold for cerebral contusion was of the order of 250 lb of force with a correspond-

ing acceleration of 640 g. The threshold for fractures and more severe cerebral damage was in the order of 500 to 1,000 lb of force, corresponding to a deceleration of 900 to 1,400 g. Interspecies scaling considerations should reduce these values in man by a factor of about one-half.

In summary, we can say that the onset of anatomic evidence of cerebral contusions requires an average of 300 g when the head is adequately restrained and padded. In fractures of 500 g coup and contrecoup lesions are present. These levels are above those needed for "sharp" limited-area impact of facial bones, which require only 30 to 100 g for fracture. If fracture or plastic deformation of the skull can be prevented, overall head decelerations of 350 to 500 g can be tolerated without serious injury.

Thoracic Cage. In this context we are referring to the ribs and their associated vertebral and sternal attachments and not to the viscera contained within them. Beekman and Palmer (44), using a rhesus monkey as a model, recorded peak forces of 700 lb as producing up to a 3-inch deflection of the anterior thoracic wall. No fractures were observed in this series. Using unenbalmed cadavers, Kroell *et al.* (45) found "severe" injury with impact forces of approximately 1,000 ft-lb with fatal results at as little as 900 ft-lb. The actual extent of the fractures and injuries were stated; they consisted of multiple rib fractures with pulmonary and cardiac lacerations.

The rib cage is able to absorb a great deal of impact energy by deformation of individual ribs, by a general downward rotation, and by transmitting loads to the thoracic vertebrae and viscera. Since there is almost always adequate upper-torso restraint found in victims of military-aviation accidents, with consequent distribution of the impact force over a larger area, quite high levels of deceleration are necessary to fracture ribs (in our experience 40 to 60 g). Loose restraints, poor prior positioning, and premature failure of one component of a restraint can adversely redistribute the load and cause fractures in accidents that have lower apparent "total body" decelerations.

CONCLUSIONS AND RECOMMENDATIONS

1. The aviation pathologist can play a role in aircraft-accident investigation that exceeds the activities previously pursued in determining cause of death and identification of the deceased. He may aid the technical personnel of aircraft-accident investigation boards in determining the cause and manner of the accident. This is true even in those cases in which pilot incapacitation and other human-factor considerations have played no part in the cause of the accident.

2. The aviation pathologist must follow a definite PLAN OF ACTION in his activities in order to seek out and organize the great amount of information available and to present it in a helpful and orderly fashion. The following is suggested:

a. Familiarize yourself with the circumstances of the accident.

b. Visit the scene of the accident or the site where the wreckage is being collected.

c. If possible, visit an intact type-model of the aircraft.

d. Perform a careful postmortem examination, paying close attention in particular to x-ray documentation of skeletal injuries.

e. Classify, organize, and analyze injuries.

f. Be careful to recognize the "odd" injury, the case that stands out from the others.

g. Make an initial calculation of impact forces with respect to magnitude, direction, and duration.

h. Formulate a preliminary, medically based hypothesis and find out whether it is congruent with any engineering hypothesis being formulated.

i. Eliminate disagreements between these two hypotheses by mutual refinement until the final formulation of the impact sequence is in accord with both the medical and the engineering data.

3. Each injury should be examined from the standpoint of --

a. The magnitude of the force required to produce it.

b. The duration of the force and whether or not the injury was caused by deceleration, by impact, or by impulse.

c. The area over which the force was applied, particularly with respect to restraints, helmets, and other life-support equipment used.

d. The composition of the impacting surfaces.

e. The direction of the force.

4. Thresholds for injury production have been discussed for abdominal and thoracic viscera, the spine, the extremities, the head, and the thorax. Additional information is needed to determine injury thresholds of the cervical spine (44), upper extremities, and small bones of the hands and feet.

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HEAD INJURY PATHOLOGY AND ITS CLINICAL, SAFETY AND ADMINISTRATIVE SIGNIFICANCE

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The occurrence of head trauma is so common that its true importance as a major statistic associated with accidental injury and death may be overlooked. A review of head trauma in war, vehicular accidents, sports, and aviation demonstrates that while the head constitutes roughly 9 percent of the body's weight, surface area and volume, it is implicated in 7 out of 10 body injuries. Generally speaking, head trauma causes an unacceptable 1 in 4 deaths and for motorcycling it causes a staggering 1 out of every 2 deaths. Head protective devices have been available since antiquity; but except in isolated circumstances they cannot be shown to have had a mitigating effect on the magnitude of the injury rate. Yet, the technology exists to prevent head-injury deaths and to greatly reduce injury severity in survivable accidents, especially in aviation.

While it is accepted that helmets, indeed, provide significant protection, most systems of accident investigation, injury analysis and data recording do not recognize head trauma as endemic or even epidemic. Thus, the problem has not been approached epidemiologically. Instead, the bulk of head injury research is directed toward improved treatment and prevention of disability. These efforts are on the secondary and tertiary levels of prevention. Head trauma is expensive, as is the technology to avert it; but the authors contend that available statistical data cannot support the cost effectiveness of preventing head injury. In the future, examination of head trauma, its costs and the effectiveness of provided protection must apply the analytic tools of epidemiology not only to the injury but to the equipment as well. Prevention requires anticipatory action, based on the knowledge of protective performance history, in order to make the onset or further occurrence of injury unlikely.

INTRODUCTION

. . . there is no such thing as an accident. What we call by that name is the effect of some cause which we do not see.

Voltaire

Accidental death from unavoidable causes is a tragedy. Death and major injury that can be mitigated or prevented, but isn't, in sane societies, is irresponsible if not criminal.

. . . if preventable, why not prevented?

Edward VII

Since the very dawn of Man, he has had the exclusive disposition to major head injury from relatively minor impacts. With the exception of only a few monkeys, the human skull alone is a comparatively delicate housing for the most vital of all organs. Man has potentially fatal mechanical flaws in his calvarium perhaps as a result of a trade-off for large brain mass and superior mental ability. A survey of the rest of the animal kingdom shows excellent protective structures such as thickened cranial vaults, high sagittal and occipital crests, protruding orbital ridges, horns and hydraulic dampers. Man's intelligence and potential for wise judgement should divert him from high risk situations that involve head impact. Ironically, man is not wise but foolish and seeks situations that place him at risk.

. . . when there is no vision, the people perish.

Proverbs 39: 18

In 1960, Dr. L. B. Leakey discovered the skull fragments of an ancient man which showed obvious fracture at the time of death. Whether from a fall or combat, we will never know.[1]

Recently, projects have been undertaken to x-ray a number of Egyptian mummies.[2] Quite often the results demonstrated violent death and a few actually showed massive head injury. The Edwin Smith Surgical Papyrus[3]

translated by Breasted in 1930 points out the extensive knowledge that the Egyptians had concerning the head and brain. (See Figure 1) They were apparently familiar with the dura and cerebrospinal fluid but generally treated head trauma expectantly. The war loving, combat seeking Indians of Central and South America created weapons specifically to inflict trauma on the head. As their tools of injury became more efficient so did their science of head injury diagnosis and treatment with skillful trephining. No longer was head trauma classified as expectant and a number of repeatedly traumatized skulls exist that demonstrate successive surgical interventions with subsequent recovery.[4]

Figure 1. Hieroglyphics describing neuroanatomy and treatment of head injury*

The actual history of mankind could have been changed except for the choice of wearing or not wearing a protective helmet. The biblical outcome of the story of David and Goliath may have been quite different if Goliath had not been too proud to wear his helmet against an opponent of such small stature as David with his sling and rock. David refused the heavy armor of Saul, opting for mobility and reliance on Divine protection.

Throughout history man has designed hundreds of different helmets to mitigate the seriousness of head impact. Each was an improvement. Coincidental with these improvements, he seems to have come up with equally effective ways of defeating the protection which he was affording himself. His tools of injury began with rocks, clubs, arrows and spears, and have evolved to bullets, bombs, missiles and motor vehicles. Man seems bent on placing his head in the path of objects with great potential energy. The single trauma producing characteristic which makes each different is its velocity. As helmets were changed from animal hide to bronze, metals to composites and finally to multilayered energy absorbers, the velocity of the impact devices increased at the same time.

As we shall see, there is minimal data to substantiate the thesis that head protective devices actually reduce mortality and morbidity rates.

HISTORICAL PERSPECTIVES OF HEAD TRAUMA

There is ample evidence in the literature to support a contention that head trauma and its resultant effects are a serious problem to the health of the world's peoples.[5 6 7 8 9 10] It is not being bold to offer that major head injury is endemic to nearly every occupation, recreation, mode of travel and even to life itself. It achieves epidemic proportions in the tragedies associated with war, aviation and vehicular transportation. The following is a cross sectional sampling of head trauma statistics:[11]

TABLE I

MORTALITY FROM HEAD WOUNDS IN WAR*

Crimean War	898 cases	73.9 %
War of Rebellion	704 cases	71.7 %
World War I	---	35
World War II	582 cases	14.0 %
Korean War	879 cases	9.6 %
Vietnam	1,132 cases	11.23%
US military	1,171 cases	9.74%
Free world and civilian	561 cases	14.48%

From 1961 to 1966 there was a 15% incidence of fatal head injury in survivable** US Army helicopter accidents, and a 15% incidence in nonsurvivable accidents for a total of 15% fatal head injury.[12] From 1967 to 1969 there was a 23% incidence of fatality due to head injury.[13] During this period, no changes in head protection took place

*After Breasted, 1930.

**After Gurdjian, 1974.

***Crash acceleration forces calculated at the floor are within human tolerance, and there is habitable cockpit structure left post-crash.

but Army helicopters became faster and smaller, and mission envelopes became more hazardous. In a survey covering 1971 to 1974, the US Army is still maintaining a 22% incidence of fatal head injury in relation to total numbers of injuries from survivable and nonsurvivable crashes.[14]

US Air Force aircraft crashes during the period 1963 to 1967 demonstrated a 19% incidence of major or fatal head injury. Considering total numbers of injuries, regardless of severity, head injury was found in 86% of the accidents.[15]

The automobile accounts for millions of injuries and fatalities. For example, in 1974 there were 2 million injuries and 55,800 fatalities. The United States National Safety Council publishes a list of accident facts each year and consistently reports head trauma occurring in 70% of the accidents involving injury.[16] Of the accidents which result in fatalities, 20-30% can be directly attributed to head injury. Helmets are not a common item of protection used by US motor vehicle occupants. Seat belts and shoulder harnesses are available, irregularly used and not statistically implicated in altering US head injury figures.

A 1974 Australian and New Zealand Journal of Surgery report states that head injury accounted for 64% of the injuries in auto accidents in 1962-63 and 72% in 1972-73.[17] It goes on to point out that 26% and 21% of these cases respectively, involved major head injury.

The Australian data in Tables II, III and IV by Jamieson and Kelly before and after safety laws had gone into effect appear to show that passive devices such as seat belts in the auto industry and helmets for motorcycle riders have had a mitigating effect on the incidence of head injury. Similar comparisons have not been made from the general US data. In unbelted drivers, the incidence of major head injury dropped from 26% to 7% in belted drivers. They also reported in a separate study that head involvement was reduced from 68% to 52% after passage of the motorcycle-helmet-mandatory-use-law.[18] Major head injury dropped from 29% to 18% after the passage and enforcement of the law.

TABLE II

INJURIES SUFFERED BY AUSTRALIAN DRIVERS*
(PERCENTAGE OF EACH INJURY IN BRACKETS)

Total Injuries	435
Major head	107 (2.46)
Minor head	176 (40.4)
Total Head Injury	283 (65.0)
Chest	125 (28.7)
Abdomen or pelvis	68 (15.6)
Spine	20 (4.6)
Limbs	159 (36.6)

TABLE III

COMPARISON OF INJURY PATTERNS OF BELT WEARERS AND NON-WEARERS IN DRIVERS**
(PERCENTAGE INCIDENCES IN BRACKETS)

CATEGORY	NONBELTED	VOLUNTARY USE	BELTED
Number of drivers	267	55	30
Major head	71 (26.2)	16 (29.1)	2 (6.6)
Minor head	101 (38.2)	27 (49.1)	16 (53.3)
Total Head Injury	171 (64.4)	43 (78.2)	18 (60.0)
Chest	91 (34.1)	14 (25.5)	5 (16.6)
Abdomen or pelvis	48 (14.2)	10 (18.2)	5 (16.6)
Spine	11 (4.1)	4 (7.3)	1 (3.3)
Limb	94 (35.2)	25 (45.4)	10 (33.3)

*Abridged from Jamieson and Kelly, 1974.
**After Jamieson and Kelly, 1974.

TABLE IV
INJURY PATTERNS OF 254 AUSTRALIAN MOTORCYCLE, MOTORSCOOTER AND PILLION RIDERS*

Injury Category	*Before Legislation*	*After Legislation*
Number of persons	151	103
Frequency of each injury:		
Arm	29 (19.2%)	19 (18.5%)
Thigh	29 (19.2%)	20 (19.3%)
Leg	27 (17.9%)	29 (28.2%)
Chest	22 (14.6%)	20 (19.3%)
Abdomen or pelvis	16 (10.6%)	19 (18.5%)
Major head	44 (29.1%)	19 (18.5%)
Minor head	58 (38.4%)	34 (33.0%)
All head	102 (67.5%)	53 (51.5%)

An analysis by the authors of the primary cause of death in 92 motorcycle accidents (Coroner's office autopsy data)[19] from the Dade County, Miami, Florida, area (Tables V and VI) where a mandatory helmet law is strictly enforced, revealed that 46% of the deaths were directly attributed to head trauma.

TABLE V
DADE COUNTY, FLORIDA
MOTORCYCLE FATALITIES

Year	Mortality Rate	Head Injury Rate
1971	28%	12%
1972	20%	9%
1973	27%	16%
1974	17%	5%

TABLE VI
DADE COUNTY, FLORIDA
MOTORCYCLE FATALITIES PRIMARY CAUSE OF DEATH
1971-1974

Body Area	Percentage	No. of Cases
Head	45.65%	42
Neck	8.70%	8
Chest	16.30%	15
Head and Chest	18.48%	17
Other	10.87%	10

Interesting data from other reporting activities further emphasizes the prevalence of head injury. The US National Ski Patrol data from 1973-1975 indicates 13% of reported primary injuries involve the head.[20] Among US high school age football related deaths, 60% are from head trauma, although the incidence appears to be decreasing as better helmets are introduced.[21]

It is disheartening when a review of the best and most recent head injury data leads to a preliminary conclusion that in an activity like motorcycling where helmet-use laws are in effect, one out of every two deaths is still

*Abridged from Jamieson and Kelly, 1973.

attributable to head trauma. No conclusion can be reached as to the reduction of nonlethal injury resulting from the use of helmets.

While mortality statistics are plentiful, the data is poor. Methods of reporting vary widely. There is a universal lack of common terminology for reporting the pathologic findings of well investigated accidents. "Multiple Injuries, Extreme" is a coroner's common excuse for failing to pinpoint the true or primary cause of death. Too often, mortality statistics reflect the effect of forces entirely too catastrophic for any survival and fail to identify those accidents which should have been sublethal or survivable.

Morbidity statistics are worse. Injury reporting and its diagnostic vocabulary are haphazard and incomplete. Head injuries that at a distant time contribute to death or significant disability are not properly identified. Head trauma morbidity is a concern of clinical medicine with early diagnosis and treatment as the objective. Cause and effect are of minimal importance. Mortality concerns the pathologist with establishing the mechanism of death as his objective. Few investigators inquire as to the external forces that perpetrated the injury. Fewer yet integrate and correlate external forces to the effectiveness of active and passive protective devices and in turn to the resultant injury.

Nevertheless, it is reasonably safe to state that 7 out of 10 of across the board aviation and motor vehicle crash injuries involve the head, and 1 out of 4 of the deaths are attributable to head injury. Intervening protective devices whether they be body restraint, structural crashworthiness or helmets indeed mitigate injury, but to what degree is unknown. Several attempts to assess degree of protection have been made. Unfortunately, the data is descriptive and is used primarily as supporting rationale for continual empirical equipment development. Sound epidemiologic techniques are rarely used by engineering disciplines to evaluate the effectiveness of a piece of equipment.

HEAD INJURY ECONOMICS

The cost of pain, mental anguish, and disability is incalculable. In the United States, the courts "reward" an accident victim's grief in the form of large cash settlements that to some observers is penitence for social guilt caused by a total inability, helplessness or unwillingness to prevent the injury in the first place. The actual medical costs can only be estimated. The National Safety Council and several major US insurance companies report 1974 automobile accident costs for fatalities (excluding liability) to be $6.3 billion and rising exponentially.[16] All head injury conservatively contributes $2.4 billion of this total. Nonfatal injury costs are estimated at $9.7 billion. Motorcycle accidents contribute 3% of the total injuries and 3% of the fatalities. Based on the same cost data, all motorcycle injuries cost $606 million with $424 million attributable to head trauma. The cost of motorcycle fatalities is $189 million of which $47.3 million is attributable to head trauma.

The raw data does not isolate those injuries or deaths that could have been prevented had protective devices been used or that were reduced in severity because of the proper functioning of a device. Thus, monetary savings from preventing mortality or mitigating morbidity cannot be determined even from localities where safety devices are legislated.

Zilioli and Bisgard using 1969 and 1970 US Army UH-1 helicopter accident data demonstrated that human costs often exceed aircraft hardware costs especially in partially survivable and nonsurvivable accidents.[22] Direct military medical care costs for 126 specific nonfatal injuries in survivable crashes for the two year period were in excess of $755,000. US civilian health care costs for these military injuries could have been estimated at $7 million had the military health care facilities not been used. Head trauma accounted for 20% of the primary injuries involved and represented 16% or $122,000 of the total treatment costs. Answers to the following questions are unknown.

a. How many of these head injury cases returned to flying?
b. How many could not return to flying because of history or sequelae that was unwaiverable by regulation?
c. How many were disabled and left the service?

Since some of the nonfatal head-injured aviators did not return to flying and had to be replaced; and some were awarded life-long compensation, the true direct costs may be double or even triple these estimates.

UH-1 fatalities from all accident classifications during 1969 had costs identifiable to the taxpayer in excess of $16 million.[22] Assuming one out of four deaths were caused by head injury, $4 million represents the head-death portion.

In the United States during 1975, an estimated 2.5 million civilian helmets were manufactured and sold for a gross sales value of $35 million.[23] Thousands of sophisticated military helmets are purchased each year at an unidentified but surely staggering cost. Has this investment in protection been cost effective?

In 1969, the total US government funded budget for head injury research was $8 million and has remained relatively stable since then.[10] Helmet research expenditures are negligible in the private sector. Nearly all the military helmet development money is spent on areas other than injury mitigation. Assuming a $55-56 million head injury research expenditure during the period 1969-75, it should be acceptable to ask:

. . . "what have the results of this expensive research netted in eliminating mortality and reducing morbidity?"

The reader should note that the cost estimates for one (1) year's motorcycle head-death fatalities nearly approximate the research expenditure for seven years.

SAFETY SALESMANSHIP

Even though it seems callous and contrary to medical ethics, the only rationale considered acceptable by administrators in support of programs of safety and injury prevention is economic and not loss of blood. They commonly ask these questions:

a. How much will it cost?
b. What are the recurring costs?
c. How much money will be saved?
d. How can you prove money will be saved?
e. How many lives will be saved?

Unfortunately, satisfactory answers cannot be provided. Less than 4% of the US government (nonmilitary) head injury research budget is for epidemiology studies.[10] Little or none of the resulting data finds its way into answering these questions.

Military aviation medical accident data is not recorded or reported with the intent of answering these questions. Thus, administrators correctly ask medical people the question, "if these suggested expensive safety features are implemented, on what basis will you evaluate the cost effectiveness of something that does not happen; or by what means can you demonstrate that the safety feature will indeed prevent the incident and injury?"

The engineering community has not met the challenge either. Protective performance too frequently is appraised on the basis of a summation of the mechanical properties of each component rather than on the performance of the system as a whole. Helmets are evaluated for impact protective characteristics using physical test methods that provide standardized, reproducable engineering data. Many of these methods enjoy international acceptance or are comparable to individual national standard methods.[24] None of the methods except that proposed by the National Operating Committee on Standards for Athletic Equipment[21] attempt correlation of the test method results with human head tolerance. Until the recent paper by Y. King Liu, et al, on Optimal Protection in Direct Closed Head Impact,[25] there has been no attempt to correlate predictive head injury modeling techniques with actual helmet development. Great emphasis is placed on investigating and mathematically modeling the biodynamics of closed head injury. Rather satisfactory optimization is achieved with fatal injuries but there are no attempts to refine the equations for nonlethal trauma. The dependent variable of performance of the protective helmet is not introduced to these models because its dynamic behavior when attached to a living head is unknown. Alterations in helmet performance that occur as a result of aging, poor maintenance, chemical degradation, abuse, or weak-link-components are not known. Yet, it is assumed that protective performance remains constant throughout the service life. US Army and US Department of Transportation helmet analysis data does not support this assumption.[26 27]

The authors conclude that it is statistically unreasonable to compare head injury data before and after the introduction of a new or improved helmet and consider the comparison as a valid representation of protective performance. Too many changes in the environment occur, not withstanding the abstractness and inaccuracies of available injury statistics.

PRAGMATIC PREVENTION

Leavell and Clark[28] define prevention as "to come before or precede," and relate it to the English dictionary explanation that to prevent is "to anticipate, to precede, to make impossible by advance provision." They contend that in disease states, "prevention requires anticipatory action, based upon the knowledge of natural history, in order to make the onset or further progress of disease unlikely." It is appropriate and valid to substitute the words, "protective performance in history," for, "natural history." Likewise, substituting, "occurrence of injury," for, "progress of disease," does nothing to alter the definition. It follows that:

> . . . prevention does require anticipatory action, based on the knowledge of protective performance history, in order to make the onset or further occurrence of injury unlikely. . .

Leavell explains that <u>primary</u> prevention is accomplished <u>before</u> the event (prepathogenesis) by taking measures to ". . . specifically protect man against disease agents, or the establishment of barriers against agents in the environment. . . ." The words "accident, impact force and helmets," can be substituted in this statement to bring the definition into proper context with this paper.

We have already shown that most head injury research deals with injury mechanics, early diagnosis, treatment, and, to a lesser degree, disability limitation and rehabilitation. Leavell would place these efforts in a classification of <u>secondary</u> prevention (after pathogenesis occurs) or <u>tertiary</u> prevention (corrective therapy).

"Epidemiology is the study of the distribution and determinants of disease prevalence in man."[29] If we interpret the definition and application of the discipline correctly, it is safe to substitute, "injury," for, "disease." The process can be extended to engineering terms-of-reference by substituting, "damage," for, "disease," and, "equipment," for, "man." Epidemiology is an applied discipline that has the descriptive component of ". . . study of distribution" and the analytic component of ". . . study of determinants." The discipline should not necessarily be viewed in the classic sense of a "medical science of treating epidemics" (Webster) although it has been shown that head injury is both endemic and epidemic in proportions. Epidemiology can be an effective tool in the hands of engineers and physical scientists as well as medical personnel.

CONCLUSION

Reduction of head-trauma deaths and prevention of head-trauma injuries in survivable accidents appears to be an achievable challenge provided that:

> . . . the statistical community, design analysts, and accident investigators use epidemiologic methods to delineate the problems of accident head trauma and to justify the economy of whatever preventive measures must be taken to significantly eliminate or reduce mortality and morbidity. . .

Thus, they must go beyond the currently used descriptive aspects of the discipline and provide analytic and predictive data from the field and laboratory:

> . . . the engineering community must accept the premise that a helmet or any piece of life support equipment, to be medically acceptable, must provide its protective function as effectively on the last day of its service life as on the day it was removed from the packing box and tested . . .

Thus, there must be changes in the orthodox test methodologies so that results correlate to field performance. These methods must yield data that is extrapable to predicting biologic injury.

> . . . the medical community must accept the research opportunity to study the most costly of all human experimentation, the accident sequence. It is insufficient to continue determining only cause of death. Sound epidemiologic principles must be mixed with failure-mode analytic techniques to directly correlate crash forces, injury pathology, mechanisms of injury and structural performance of protective equipment . . .

These data must then be used to optimize mathematical models of head injury and provide precise recommendations to designers.

> . . . the designers in turn must approach head protection from a systems viewpoint. The goal is not a helmet that gives acceptable physical test results but acceptable protective performance when mounted on a living head in the crash environment . . .

The authors contend that in environments where safety education is accepted and use of protective equipment can be regulated, the current and historical incidence of head trauma morbidity is unacceptable. Death resulting from head trauma in survivable crashes is inexcusable.

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NEUROPATHOLOGY AND CAUSE OF DEATH IN U.S. NAVAL AIRCRAFT ACCIDENTS *

by

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SUMMARY

A frequent cause of death in naval aviators is hypothesized as drowning, associated with "acceleration concussion" perhaps due to neck stretch. Present autopsy procedures on aviation accident fatalities could be improved in order to investigate this hypothesis.

Aircraft accident fatality data for the U. S. Navy are presented as a measure of the population at risk and recent data from the literature which might explain the causative mechanism of acceleration concussion is presented. Recommendations for improved standard autopsy protocols for aircraft accident fatalities are presented.

INTRODUCTION

Crash fatalities to aviators represent a continuing drain upon available resources which to some considerable extent is preventable. Intensive study of accidents and injuries, both fatal and non-fatal, has been carried out by the U. S. Navy in aircraft accident boards for many years with the results of the investigations coded and stored in computers by the Naval Safety Center. This represents a rich resource for determination of the epidemiology of fatal injuries. The number of accidents of unknown cause amounts to 40% considering only fatal accidents, as Mason mentioned in 1962 (1). The same author continues: "In these circumstances, facts can be established by deductive reasoning only and it is reasonable to suppose that an experienced appraisal of the findings within the dead body will give evidential support comparable to that based on the findings in the 'dead' machine".

EPIDEMIOLOGY

In 1963, Ewing observed that naval aircraft crashes might be associated with concussion due to neck stretch (2). This was suggested by the work of Friede (3, 4, 5). In the discussion after the paper, CAPT Richard Luehrs MC USN stated that: "In recent years, I have seen 11 planes float by the side of the carrier with the pilot sitting in the cockpit making no attempt to get out. In this type of accident, there is no place where the pilot can hit his head unless it is laterally. I think it would be very unusual that a flier would hit his head laterally when the plane is moving straight ahead. I do not think he is hitting his head on anything. I think he is breaking his neck with the weight of the helmet when the moving plane hits the water" (2) - p 118.

This represented the experience of just one flight surgeon albeit a most experienced one. Other similar cases may not have been reported by flight surgeons.

Such cases would not ordinarily be reported or coded by the Safety Center as such, since such a pilot would be recorded only as lost at sea, with only a rare recovery of the remains (about 90% are not recovered) (6).

In order to further investigate this problem, Naval Safety Center was queried as to various statistics. Their reply (reference 6) was analyzed by Ewing.

These data showed that in the five fiscal years, 1959 through 1963, there were 6,974 individuals involved in aircraft accidents involving ejection, bailout, collision with ground and collision with water (which also includes ditchings), of whom 89% were exposed to crash impact accelerations of collisions with ground or water while only 11% avoided them by ejection or bailout. Furthermore, 70% of all fatal jet embarked accidents, and 88% of all fatal prop embarked accidents were collisions with water, while only 22% of all jet embarked accidents and only 51% of all prop embarked accidents were collisions with water. The total number of fatalities during this period from collision with water alone was 226.

With this evidence of the severity of the problem in the Navy, a working paper was prepared in which it was attempted to determine the cause for the high fatality rate (7). In part, it stated:

"In attempting to determine a reason for the experience quoted in the first paragraph, a study of the literature combined with a study of the aviator's situation during a crash provided the following:

1. The aviator's head and neck are unrestrained, permitting relative motion in a deceleration event between the restrained torso, and the unrestrained head and neck.

2. The crash helmet, worn in all carrier aircraft, has a center of gravity location which shifts the center of gravity of the head-helmet mass superiorly and anteriorly. This would tend to increase the rotational moments of the head on the neck.

3. The crash helmet adds 50% in weight to the normal weight of the head, thus increasing markedly the force exerted on the neck in a deceleration event.

4. According to reference (3), 'both the typical symptomatology and the pathology of acceleration concussion can be reproduced by other means than by applying a blow to the head; that is, all the typical signs of experimental concussion can be reproduced without applying a blow to the head; for example by cervical stretch. Cervical stretch has been shown to exist in acceleration concussion. An experimental analysis of the various mechanical factors involved reveals that stretch and flexion of the cranio-cervical junction are most important for the mechanics of concussion'. Acceleration concussion is defined for purposes of this discussion as concussion occurring in an individual with a freely moveable head (i.e., unrestrained and not resting against anything) who does not receive a blow to the head and who does not suffer cortical injury.

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* Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the view or the endorsement of the U. S. Navy nor the sponsoring organizations.

5. The neuropathology involved is a circumscribed fiber lesion at the ventral circumference of the 1st cervical segment (in cats). To demonstrate this lesion, the brain and spinal cord must be removed without transection and the region between the caudal end of the fourth ventricle and the second cervical segment should be cut serially in longitudinal sections. The intensity of fiber damage in the cord is paralleled by the extent of cell changes in the medulla oblongata, the latter arising from the former.

6. In order to study the neuropathology of concussion in any animal (including man), it is necessary to (a) cause the injury, (b) wait several days to allow axonal and neuronal changes to occur, then (c) sacrifice the animal, (d) remove the brain and cord intact, and (e) prepare tissue sections for microscopic study. Since we rarely, if ever, have this exact chronology in human aviation fatalities, we must accept the fact that the basic data on which decision must be made will be that from animal experiments.

7. In reference (2), concussion produced by sudden deceleration from a velocity of the head of 25 mph produced reflex abrogation for durations of 60 seconds or longer, and the duration of loss of consciousness always exceeded the duration of reflex abrogation. It should be noted that studies on jet aircraft have shown that the aircraft usually sinks within 60 seconds" (8).

NOTE: Rawlins, et al found that jet aircraft float only for a maximum of 1 minute, and after sinking descend to the bottom at a minimum rate of 400 ft/min thus giving a maximum of 2 minutes for the aviator to escape before being crushed by water pressure (3).

"Therefore, it appears probably that the explanation for CAPT Luehrs observations is that: (a) aviators can be rendered unconscious by acceleration concussion, probably not due to nor accompanied by cervical vertebral fracture or to head injury; (b) that such acceleration concussion can easily be produced in collisions with ground or water; (c) that the expected duration of such unconsciousness would exceed the time necessary for the aircraft to sink; (d) that the concussion produced was made worse by present helmet design and lack of head-helmet restraint; (e) that the aviators, therefore, died from drowning rather than head or neck injury per se; (f) that a majority of naval aviators suffering collisions with ground or water are exposed to the risk of this hazard; (g) that a majority of fatalities from jet and prop embarked accidents occur in accidents (collisions with water) where this risk is present; (h) that only 10% of the remains of such fatalities are recovered so that no pathological study of the remains is possible; and (i) that therefore this problem has previously been unrecognized in naval aviation as such.

In attempting to find a means of preventing acceleration concussion, reference (9) states that -- 'these high linear accelerations did not result invariably in concussion when the cervical spine was immobilized. Acceleration of 930G failed to cause concussion. It became evident that concussion was produced more easily when the head was free to move on the neck'.

Therefore, research and development effort must be initiated on a high priority basis with the following phases and objectives:

1. Determination of exact information, usable by engineers, concerning the production of acceleration concussion in animals.

2. Utilization of this information to design, manufacture, and evaluate protective equipment (such as head-helmet restraint gear) which will protect against this hazard in appropriate aircraft systems.

3. Evaluate the equipment answers to the problem on human subjects on (experimental) acceleration devices.

---- This problem, though not peculiar to the Navy, is of greater importance to the Navy than to most other agencies (due to the high proportion of fatalities in embarked collisions with water). A multidisciplinary approach is mandatory, including such diverse fields as neurosurgery, mechanical engineering, research aviation medicine, human engineering, neuropathology and impact physiology.

Although it is well known that a certain number of Naval aviation accidents are of such a nature that the pilot has no chance for survival, it is possible that a very large number are survivable that are not now being survived. It is quite probable that a satisfactory solution to the problem delineated in this paper can decrease the fatality rate in Naval aviation more than any other single improvement in sight, with the possible exception of a successful rocket ejection seat and even that would be limited to jet aircraft."

This early, somewhat simplistic analysis, contained several concepts leading to the work which followed.

In order to get more precise data of more recent data, a study was undertaken of FY 1967 to determine all aviator losses; the type of accident; cause of death; and autopsy results (if performed) using Naval Safety Center data (10). The object of the study was to investigate the possible means which might have prevented the fatality, given the knowledge of what caused it. Many results have flowed from this study, including the development of a major aeromedical research program designed to develop the human data necessary to evaluate candidate protective devices against the known causes of fatal injury. Several findings of that study are now being more thoroughly investigated, and one of these is the problem of drowning in an accident which otherwise might not have resulted in significant injury, as outlined above.

The study showed that in FY 1967, two hundred and twenty-eight (228) Designated Naval Aviators were killed, lost at sea, missing in action or fate was unknown as a result of aircraft accidents, both combat and non-combat. Of the total, two hundred and twenty (220) were either pilot or co-pilot and were thus in a predetermined location at time of aircraft accident. Of this number, only forty-one (41) ejected and two (2) bailed out. The remaining one hundred and seventy-seven (177) individuals crashed in their seats.

Ninety-six DNA's of whom 4 ejected were involved in the single accident type of collision with ground or water. Examination of known causes of death for these individuals revealed that 26 were lost with the aircraft, details unknown, 5 more were lost at sea not in the aircraft, and 4 more were drowned. Therefore, thirty-eight percent (38%) of the ninety-two (92) personnel were lost at sea, drowned or lost with the aircraft.

It is probable that some of these pilot losses were due to temporary unconsciousness or concussion due to the crash, rendering them unable to escape from the sinking/burning aircraft.

During the course of the FY 1967 study, (conducted in FY 1968), it was determined that autopsies were being conducted by general pathologists at hospitals nearest the accident site; that the examination did not necessarily include x-rays or photography prior to the autopsy, that frequently CNS examinations were not done at all; and that aviators who survived for a number of days following the crash but subsequently expired were infrequently subjected to autopsy and almost never to a CNS postmortem examination. Furthermore, remains recovered from the water after days of immersion were frequently treated in the same fashion.

Death from burning is another frequent and important hazard of aviation accidents. Thermal burns rank with cranio-cervical injury as the most frequent cause of aviation deaths after multiple injuries. Combined mechanical and thermal trauma frequently occur. Unfortunately, a detailed and comprehensive study of damage to the central nervous system due to thermal burn does not exist.

Some of the described pathomorphological alterations due to burns, however, are similar or identical to secondary traumatic or hypoxic alterations due to mechanical trauma.

In summary, most aviation autopsies have not resulted in satisfactory neuropathological examination of the central nervous system.

An autopsy of the crash victim must show not only the cause of death, but also a concise description of the distribution and quality of the tissue alterations in brain and spinal cord which can be considered the morphological endstates of mechanical trauma inputs including thermal injury.

In view of this analysis of the magnitude of the problem; and of the shortage of neuropathologists in the Navy; and of the lack of knowledge of aviation pathology on the part of, or guidance to the hospital pathologist, it became apparent that the most important source of human pathological material required to establish the presence or absence of the acceleration concussion histopathology, or even the possible mechanism of production of it, mentioned above, was being neglected.

It was, therefore, decided to undertake a more profound search of the literature of possible mechanisms of production of acceleration concussion to aid in making recommendations as to specific autopsy protocols of aircraft accident victims which might be more productive of evidence which could support or reject these possible mechanisms.

The purpose of this paper is to present the results of this research, along with some preliminary results of experimental studies on animals at this facility, and resulting neuropathological considerations and recommendations for improvements to autopsy protocols.

NEUROPATHOLOGICAL CONSIDERATIONS

Association of Cerebral and Cervical Injury

More attention has been drawn to the common association of cerebral and cervical cord injury. Too often the latter is overlooked. It is useful, therefore, to quote and analyse the papers which were published on this matter.

Leichsensing (1964) found that in 20 unselected autopsies of lethal head injuries, hemorrhages of the spine and spinal cord could be observed macroscopically and microscopically in every case, regardless of the severity of the head injuries or of the existence of skull fractures (11). In six cases, ruptures of the anterior or posterior longitudinal ligaments were seen. Traumatic disc ruptures occurred at the level of C4/5 and C5/6. In the majority of cases peridural hemorrhages were observed, which extended into the intervertebral foramina bilaterally, without predominence of any single segment. Only in the most severe injuries with complicated fractures of the occipital bones were ruptures of the ligaments of the atlanto-occipital joint and atlanto-axial joint seen. In cases of less severe head injuries, the caudal segments of the cervical region were more frequently involved. Small hemorrhages could be seen in the spinal cord too, in cases of minor injuries.

Gosch et al (1970) reported that petechial hemorrhages at the cervico-medullary junction were noted in football players who sustained direct "head-on" or vertex impacts when they struck an opponent (12). Similar head and cervical spinal cord injuries were produced in experimental animals on an impact track simulating this mechanism. Severe cervical spinal cord destruction could be obtained in the absence of cervical flexion and extension. Cord movement was enhanced by sectioning the dentate ligaments, which prevented these lesions. These authors postulated that the transmission of shear strains along the axis of acceleration was responsible for the hemorrhages when the elastic deformation limit of the cervical spinal cord was exceeded.

Davis et al (1971) reported a series of 50 fatal cases of craniospinal injury and reviewed them with particular attention to the pathological findings at the craniospinal junction (13). There was marked tendency for the spinal cord to be damaged in the upper cervical segments, whereas disc injuries predominated in lower cervical segments. The vertebral arteries were rarely involved. The lateral ligamentous structures were often damaged, while the transverse ligaments of the odontoid were spared. Rupture of muscles was rare, although hemorrhage into muscles was common.

A series of 146 victims of fatal traffic accidents were subjected by Alker et al (1975) to postmortem radiographic examination prior to medico-legal autopsy (14). A total of 42% were found to have radiographically demonstrable head injuries ranging from relatively simple linear skull fractures to massive skull damage. Free intracranial or intravascular air was demonstrated in more than 60%. A total of 21% had demonstrable neck injuries, most of which were localized to a single level at the craniocervical junction or in the area of the upper two cervical vertebrae. Flexion and extension studies of this area were of major importance in demonstrating the injury and locating potentially occult lesions for the forensic pathologist.

Alterations in the spinal cord near the occipito-cervical junction were reported in animal experiments in which different species of animals had been subjected to impact acceleration.

Denny-Brown and Russell (1941) and Denny-Brown (1961) have noted that occasionally animals concussed experimentally showed petechial hemorrhages in the cervical cord, and in their experiments movements of the head were purposely restricted to 4 cm after the blow to minimize this possibility of cervical damage (15, 16).

Unterharnscheidt in 1963, 1970, and Unterharnscheidt and Sellier (1966), reported on a large series of rabbits and cats who had been subjected to subconcussive and concussive acceleration both in the +Gz and +Gx vectors (17, 18, 19). They found that occasional smaller petechial hemorrhages in the gray and white substance of the spinal cord at the occipital-cervical junction could be observed. This author explained these pathomorphological findings as the result of marked stretching movements at this junction due to the impact acceleration of the skull.

Friede (1960) investigated the central nervous system of cats in which an abrupt stretch of the cervical vertebral column had been performed (3, 4, 5). The same type of brain stem damage was found as had been described following experimental concussion: a chromatolysis appeared in the large neurons of the reticular formation and Deiter's nucleus: In severe injuries it also appeared in the red nucleus and some other nuclei. The motor nuclei of the cranial nerves were not involved. He found also a significant fiber damage in serial studies of the cervical spinal cord. Thick fibers in the medioventral portions of the cervical spinal cord were affected exclusively. This damage was maximal at the atlas level

but sparse above this level. The locally defined fiber damage corresponded to the distribution of chromatolytic neurons sending their fibers through the damaged area and both findings were quantitatively related. Changes in the fiber structure were found also in cats killed by experiments.

X-ray investigations revealed an intimate spinal cord-bone relationship at the level of the damaged area of the spinal cord. In particular a straining of the spinal cord around the odontoid process occurred in forced position changes of the head and could be enhanced by a subluxation of the odontoid process.

Friede found also identical neurohistopathology in dropped cats subjected to an abrupt stretch of the cervical spinal cord and in control cats receiving a blow to the head. The chromatolysis in the neurons in both the stretching experiment and in cats receiving a blow to the head, is most probably a retrograde degeneration resulting from the fiber damage in the spinal cord. Friede concluded: "Therefore, a specific mechanism of cord injury at the atlas levels seems responsible for many instances of so-called 'brain' concussion".

Unterharnscheidt and Higgins (1969) carried out carefully controlled studies of non-deforming angular acceleration in the +Gx vector over 45° angle (20, 21). Location and quality of brain lesions was reasonably predictable from the mechanical input to the CNS. These pathologic changes consisted of subdural and subarachnoid hemorrhages; tearing and avulsion of veins and arteries in superficial cortical layers leading to rhectic hemorrhages; partial and total traumatic necroses; and rhectic hemorrhages in cranial nerves. With the exception of a few animals, the spinal cord showed small rhectic hemorrhages in various segments through its entire length, extending to the cauda equina. It was demonstrated that a difference in quality existed between primary traumatic cortical hemorrhages associated with angular acceleration and the so-called cortical contusions found in translational trauma. A difference was noted in the patterns of distribution of the primary traumatic cortical contusions encountered in angular as opposed to translational acceleration. It was demonstrated that a non-deforming rotational acceleration of the head could produce leasions not only in the brain but through the entire length of the spinal cord.

There exists no doubt for us that the alterations described by Denny-Brown and Russell (1941), Friede (1960), Denny-Brown (1961), Unterharnscheidt (1963) and Unterharnscheidt and Higgins (1969) are intravital; they are not artifacts (15), (5), (16), (17), (20, (21). The latter two authors were able to describe mesodermal-glial reactions in animals which survived for several days. In accordance with Spielmeyer, this reaction is the result of destruction of nervous parenchyma; the destroyed tissue is replaced by a mesodermal-glial scar (22). A further indication for the fact that these alterations are intravital can be drawn from the fact that the tissue damage is dependent upon the intensity of the applied forces. These tissue alterations, especially those in the lower medulla and the cervical spinal cord, are the morphological endstates of different types and intensities of mechanical trauma. But further experimental work is necessary to clarify whether these tissue alterations are a substrate which is typical and pathognomonic of cerebral concussion, or whether they are the result of different types of mechanisms which lead to stretching or extreme rotation of the occipito-cervical junction. Unterharnscheidt (1963), (1970) and Unterharnscheidt and Higgins (1960) are of the opinion that the described lesions are not a substrate which is present in an uncomplicated cerebral concussion or a commontio cerebri, but that they occur in certain injury types, mechanisms, vectors, or intensities of impact acceleration which produce extreme stretching and rotation at this junction (17), (18),(20), (21). Further evidence for this opinion can be found in new data from recent unpublished animal experiments at NAMRL Detachment, New Orleans, Louisiana, with whole-body -Gx acceleration exposures of Rhesus monkeys with restrained torso but unrestrained head and neck (23). Each of the injury types and vectors of the effective acceleration lead to a typical predictable injury pattern with respect to distribution and quality of the tissue damage.

The preponderance of evidence presented, therefore, demands that in clinical circumstances in which humans are subjected to severe acceleration of the unrestrained head, the spinal cord as well as the brain should be examined histopathologically and that the upper cervical cord should be examined en bloc with the brain.

Present Autopsy Procedures

Present instructions for Naval autopsies are not mandatory and are in effect only routing instructions for the results (24),(25), (26), (27). X-rays are not mandated for any autopsy case but only for all ejections, ditchings, or crash landings where "significant forces were present" (25).

A suggested technique for removal and examination of the spinal cord and vertebral column is presented in (27) pages 182 - 184, dating back to 1962. It was recommended that the spinal cord is best exposed through a posterior midline incision, extending from the base of the head to the sacrum. The dura mater should be left with the spinal cord. It was stressed, however, that a laminectomy should not be done on the first cervical vertebra, but that this region should be tunneled, since any interference with it will destroy the rigidity of the connection between the head and the trunk.

It was not mentioned at which level the spinal cord should be severed from the lower medulla of the brain. This is a very important point, since the area between lower medulla and upper cervical cord is in the zone of the most extensive stress, as is shown above and as demonstrated also by Clarke et al (1972) (28).

Recommendations for Standardization of Autopsy Procedures in Aircraft Accident Victims, Derived from the Studies Reported Above

The procedure enumerated below will be performed on the following decedents:

1. All personnel suffering fatal injury due to aircraft accident, including drowning victims.
2. All personnel injured in aircraft accidents who die subsequently in a hospital.
3. All personnel who die within 30 days following their involvement in an aircraft accident.

Radiographic Examination - A postmortem radiographic examination should be carried out routinely on all fatalities resulting from aircraft accidents to include (1) anteroposterior, lateral and basilar views of the skull, (2) anteroposterior and lateral views of the cervical spine, (3) tomographic studies when necessary, (4) chest, abdomen, pelvis, extremities, and other regions of the spine when considered necessary on the basis of visible injuries.

CNS Autopsy Technique

Techniques for removal of brain and spinal cord in necropsies vary to some degree. But in order to describe, evaluate, quantify and compare the morphological endstates a standardization of the techniques used is a necessity.

As a result of the studies reported above, a more comprehensive autopsy must be performed on the remains. This should include, but not be limited to, a detailed gross and microscopic examination of all injured organs exclusive of the central nervous system, which will be handled separately as described below. It should also include a description of the status of both common and internal carotid arteries and both vertebral arteries. In case of an evident injury to these vessels, the entire specimen should be forwarded.

The brain and spinal cord down to the cauda equina must be removed in toto, leaving the unopened spinal dura mater on the specimen, using a posterior incision and laminectomy. This is quite important because the level of the cranio-cervical junction is suspected as a frequent site of fatal injury in naval aircraft accidents but ordinary autopsy procedures destroy this vital area. A cut may be made at the cervical-thoracic junction.

Section of or dissection of the unfixed fresh brain should not be performed at the autopsy table.

The specimen should then be fixed in 10% neutral buffered formalin for about two weeks and then shipped.

The pituitary should be removed and fixed in 10% neutral buffered formalin.

After photographing and describing brain and spinal cord a Spielmeyer assortment of tissue blocks for histologic examination should be cut.

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CLARIFICATION OF A FATAL HELICOPTER GROUND ACCIDENT THROUGH FORENSIC MEDICAL METHODS

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SUMMARY

Even nowadays, though not as frequently as during the early days of aviation, there are accidents caused by propeller strikes. Technical personnel are especially jeopardized during helicopter test runs. Based on the investigation of a fatal helicopter ground accident, which was clarified through forensic-medical methods, problems of accident prevention are pointed out, especially the conspicuity of rotating propellers, tail rotors and safety markings. Moreover, there is a discussion of dangers encountered as a result of vigilance and concentration disturbances in personnel caused by stress of noise, workload and distraction. Safety measures required are also presented.

In the early days of aviation, injuries sustained by ground personnel being hit by moving propellers were a frequent occurrence, particularly when swinging the airscrew by hand. Since the introduction of the electric starter this hazard in propeller-driven aircraft has practically been eliminated. Nevertheless, there are occasionally injuries caused by rotating propellers if aircrew and ground personnel or flight passengers and other persons fail to maintain the necessary safe distance to the engines. Disturbances and impairment of vigilance through airsickness, excess of zeal and distraction have led to several serious and often fatal injuries through propeller- or rotor blades during the recent years. In this regard smaller helicopters, whose moving rotor blades are installed in the same height as a person's head, have turned out to be a special hazard.

It is often difficult to notice fast turning propellers or tail rotors. In most instances they appear to the eye only as a disc-like screen, which may more or less escape attention - sometimes even completely -, depending on illumination, angle of observation, and background. To improve the conspicuity of moving propellers and rotors for the purpose of accident prevention, markings of blades with partly colored, transverse strips have been employed with varying success.

Recently WHITESIDE (1973), after having performed a series of tests, suggested to provide vertical propellers with a black and white marking scheme, giving the impression of a white ring at the periphery of the disc and of a black ring next to it.
The other six markings per blade are painted in such a manner as to give rise to a sensation of flicker at 1000 rpm. For whirling tail rotors the marking pattern must be altered only slightly to make them conspicuous.

When a person fails to stay clear of the propeller- or rotor danger zone, most serious injuries result. Propeller- and rotor injuries are thrust wounds having in the majority of cases only a small margin of contusion at the rim of the wound, analogous to the blade construction. Due to high blade rpm, injuries are nearly always of a multiple nature and may, depending on how often the human body had been struck by the propeller- or rotor blades, comprise single injuries up to complete mutilation of the body (KREFFT). The hazard is especially great for ground staff during ground check runs and blade tracking of helicopters. That even technicians experienced in handling helicopters may make fatal mistakes if concentration is impaired by stress of noise, excessive workload, and distraction is illustrated by the following case:

At a maintenance squadron of an army aviation unit a ground check run was performed on a helicopter (Type Bell - UH 1D) for main rotor- and tail rotor blade pitch adjustment. The helicopter was parked on the apron with the tail pointing towards the hangar. To facilitate handling during blade tracking it had been parked on a slightly inclined plane so that the ground - tail rotor clearance was less (only 165.5 cm) than normal (188 cm).

During blade tracking the NCOIC of a maintenance echelon, a Master Sergeant, approached from the personnel exit of the hangar gate and walked 2.00 to 2.50 meters to the right and parallel to the longitudinal axis of the helicopter in the direction of the cockpit. He did not wear any noise defenders. Probably he wanted to talk to the 2nd mechanic working on the helicopter, since he needed him for some other work. Abreast with the tail rotor he turned left and at an angle of approximately 90° to his former direction made three to four quick steps without hesitation straight into the path of the tail rotor blades. The impact of the tail rotor blades caused severe head injuries resulting in death at the scene of the accident.

Aviation pathological examination of the corpse of the 180 cm tall man revealed as essential findings signs of multiple, edge-like violent force onto the skull with comminuted fracture of the vault in the region of the frontal bone and in the anterior region of the parietal bones, also destruction of the frontal cerebral lobes. In other cerebral regions haemorrhages and contusions were discovered. Important for the reconstruction of the accident sequence was the examination of the vault fragments distributed on the tarmac by the rotor blows. Upon maceration, ten bone fragments of different size could be pieced together to form a palm-sized portion of the calotte. This reconstructed calotte segment incorporated 9.5 cm of the coronal suture and 4 cm of the saggital

suture. The sutures had bursted. The skull fragments of the frontal region showed in part more extensive chip-off at the external lamina than at the internal lamina, pointing to a force acting from below. In a line slightly oblique to the coronal suture and at a distance of 3 to 5 cm from it, progressing from the posterior right to the anterior left, there was a black trace along the margin of the bone fracture stemming from the grease pencil, which had previously been used during blade tracking to mark the blades of the tail rotors.

From these findings it could be concluded that the first blow of the tail rotor had struck the right temporal region of the victim and, after crossing the coronal suture, had penetrated the frontal bone at an angle of 120° to the longitudinal axis of the cranium. In consequence there must have been a deviation in the direction of the head and thus from the line of sight at the moment of the accident, amounting to 30° to the left from his direction of march.

No recent injuries were noticed on his trunk and extremeties, On his right leg there was a state concurring with an old, healed fracture of the lower leg. A special finding were anomalies in the course of the basic cranial arteries.

In the blood taken from the femoral vein an alcohol concentration of 0.45 g ^{o}/oo could be proven. In the blood of the cranial cavity opened by eight blows the blood alcohol concentration amounted to slightly above 0.3 g ^{o}/oo. Examinations of the blood samples for carboxydhaemoglobin and of cerebral matter for drugs yielded negative findings.

According to investigations the victim was an experienced and composed technician known as being quiet and discreet, who himself used to give routine instructions to personnel on safety regulations. He was also well informed about the special placement of the helicopters during blade tracking with reduced ground clearance of the tail rotor. Hence, the question of a possible disturbance of his vigilance and concentration stood in the foreground during the accident investigation.

It was found, that at that time the victim in his capacity as echelon leader of the aircraft maintenance crew had been under considerable stress in his line of duty. He was responsible for the work of the aircraft maintenance crew. For reasons of reorganization, a work situation had arisen at that time which imposed a higher workload than usual on the entire maintenance personnel over a longer period of time. Investigations revealed that the victim had consumed two bottles of beer during lunch-time approximately 1 1/2 hours prior to the accident.

Most likely the M/Sgt had approached the helicopter to detail the 2nd mechanic for another urgent assignment. Upon recognizing that the man he was looking for was staying on the left side of the air vehicle, he turned left in the direction towards the tail rotor. Without ear protection, he now found himself within the helicopter noise area, in which orientation by means of hearing is no longer possible, as shown by noise level measurements. Subsequent measurements indicated values above 90 db (A). Sound pressures of this magnitude may have effects on the autonomic nervous system with disturbances in concentration and performance. The movement of the head 30° to the left may be explained - as substantiated in the investigation - by the fact, that in this moment a person known by the M/Sgt appeared on the apron, causing an additional distraction. Perhaps the blood alcohol concentration of 0.45 g ^{o}/oo may also have exerted a negative effect on his apperception in the presence of an anomaly of the basic cranial artery.

The conclusions to be drawn from this tragic accident have been laid down in the recommendations for accident prevention by the accident investigation board.

1. Experiences contained in the AGARD-AR-56, on Markings for Propeller Conspicuity should soon be put into practice and air vehicles of the Federal Armed Forces (Bw) equipped with propellers and rotors respectively should be marked accordingly.

2. On air vehicles being operated on the ground, on which technical personnel are working, the position lights should be switched on "flashing bright".

3. The adoption of an external ground crew intercom (long wiring connection) for technical personnel should be expedited.

In addition the Army Aviation Unit concerned has immediately initiated special marking for ground check run areas, which doubtlessly meets the requirements of exerting a warning signal effect. This marking consists of a disc of 24 meters in diameter, limited by a twin ring in red fluorescent paint. The area of the circle is marked by white diagonal strips save one sector located towards the cockpit portion. The external twin ring shows broken segments in red fluorescent paint.

To achieve on optimal safety effect, strict regulations have been promulgated relating to walking and driving on ground check run areas marked as such.
It has also been emphasized that anyone moving in the noise area must protect his ears by wearing earmuffs. Moreover, specific instructions have been issued concerning the positioning of mechanics, pilots, safety guards, and stand-by fire guards during ground check runs.

In the light of occupational medicine these accident prevention methods should be augmented to ensure that technical personnel, particularly when working in danger zones and in addition being exposed to noise stress, will not be overburdened through work or official responsibilities. Not only physical, but also psychic fatigue will cause disturbances in apperception, coordination of movements, vigilance and concentration, mental faculty and level of activity, which in turn may invite hazardous actions. Particularly stressful work situations should be managed by appropriate organization in such a way as to avoid physical over-tasking of personnel.

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FATAL HELICOPTER ACCIDENTS IN THE UNITED KINGDOM

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SUMMARY

The Department of Aviation Pathology investigated 27 fatal helicopter crashes in the United Kingdom in the years 1956-75; there were 52 deaths and 15 survivors. 25% of the crashes were survivable and produced 15% of the casualties and 73% of the survivors. 44 men were killed in the non-survivable accidents and 4 escaped by good fortune. 8 men died in the 6 survivable crashes; 5 drowned, one died from fire, one died from traumatic asphyxia and one submarined out of his safety harness. These 8 lives might have been saved by better buoyancy devices, better early rescue facilities and redesigning safety harness to include a crutch strap; the casualties emphasise the need for further improvements in training and in helicopter crash worthiness, and for the best early rescue facilities that can be provided.

HELICOPTER ACCIDENTS

A "survivable accident" may be defined as one in which the impact forces do not exceed the limits of human tolerance - although these limits are not easy to define and the forces involved in an accident often difficult to determine - and in which there is sufficient space left within the fuselage for the occupants. Helicopters are relatively "low and slow" aircraft, so the impact forces in an accident are likely to be low and one would expect a high proportion of survivable accidents and of survivors. But the proportion of survivable accidents was nearly the same in both rotary and fixed wing aircraft when 1200 U.S. Army major accidents occuring in 1957-60 were examined (Reference 1) namely 97.7% and 96.5% respectively.

This indicates that rotary wing aircraft are less crash worthy than fixed wing aircraft. They are less efficient and sometimes cannot afford the weight penalty of greater strength. The rotor and its heavy drive mechanism need to be mounted ontop of the fuselage and may crush the occupants if the fuselage collapses at impact. The crew sit in the front of the aircraft surrounded by the largest possible transparencies, which give an excellant field of view but little protection in an accident. Fuel tanks are often in the bottom of the fuselage and easily damaged, so that there were many deaths from burning before "crash worthy" fuel systems were introduced.

PRESENT SERIES

The Civil Aviation Authority in the United Kingdom records all accidents in which any person suffers death or serious injury, or the aircraft receives substantial damage; Table 1 shows that 10% of the 132 accidents recorded between 1958-74 were fatal. The Department of Aviation Pathology has investigated 8 of these civilian crashes and 19 military crashes, as shown in Table 2. The numbers in this series of 27 are small, and so percentages are given to the nearest 1% and do not always add up to exactly 100%.

CAUSES OF ACCIDENTS

The cause of the accident was mechanical failure in the air in 11 accidents, and apparently "pilot error" in another 11 - as shown in Table 3. The causes of the other 5 accidents were not established, but it seems not unlikely that the 2 accidents to students on training flights resulted from pilot error and the 2 accidents to experienced pilots on cross country flights from mechanical failures.

In the remaining accident, the helicopter crashed from about 600 ft some 3 minutes after take-off; the pilot was not suffering from asthma at the time of his death, although he had suffered from it in the past and had an inhaler and a bottle of antispasmodic inhalant in his pocket. The autopsy showed that he was very much overweight. Histological examination showed a few tiny foci of myocarditis, and an infiltrate of chronic inflammatory cells around small vessels in the brain. These changes were not acute and were considered to be incidental; a medical cause for the accident was not demonstrated conclusively, but his sub-clinical ill health may have contributed to an error of judgement or handling although the technical examination did not exclude a mechanical failure.

In only 2 other accidents were factors found which might have marginally affected the judgement of the pilot. Autopsy specimens from a pilot who crashed after take-off one afternoon showed a blood alcohol level of 28 mg per 100 ml and a urine level of 40 mg per 100 ml, attributed to lunch time drinking. Another pilot who flew into electricity cables one morning had a blood alcohol level of 13 mg per 100ml and a urine level of 29 mg per 100 ml, which was considered to be evidence of ingestion of alcohol some hours beforehand; enquiries revealed that he had been to a party the night before, but had strictly observed the rule about not flying for 8 hours after drinking. In no case was there any evidence of a pilot being affected by carbon monoxide or by drugs.

SURVIVORS

There were 15 survivors in the series, 4 who escaped from non-survivable accidents by pure good fortune and 11 who escaped from the 7 survivable accidents, as shown in Table 4. 8 men escaped from helicopters which had crashed into the sea and one pilot who had crashed on the runway of an airfield during an air display was saved alive from the burning wreckage by the rescuers.

CAUSES OF DEATH

The fates of the casualties are shown in Table 5; most of the naval personnel were retained uncrushed in the fuselage, whereas in all the other accidents roughly half the casualties were crushed, a quarter retained uncrushed and a quarter thrown clear because the harness or its mountings failed. This difference reflects the relatively gentle impact forces in crashes occuring at sea.

Similarly,in Table 6 the land crashes show a high proportion of multiple injuries. There were 6 deaths from head injuries; these were so severe that protective helmets could not have saved lives, although in fact only 2 of the 6 wore helmets.

Table 7 emphasises that a third of the naval deaths were caused after impact by drowning whereas in the other groups nearly all the fatal injuries occured at impact. By contrast, about half the U.S. Army helicopter fatalities in 1970-71 were post impact deaths, one third of them from burning (Reference 2); this may be related to combat conditions. It is also noticeable that in the U.K. series there was post impact fire in two thirds of the non-survivable accidents but only one third of the survivable accidents, as Table 8 shows.

DEATHS IN SURVIVABLE ACCIDENTS

The proportion of deaths occuring in survivable crashes in the 2 U.S. Army series 10 years apart (References 1 and 2) decreased by about a third from 46% to 29%, possibly following the introduction of crash worthy fuel systems and other improvements. The figure for the U.K. series is 15%, about half the later U.S. Army figure. This may be because the helicopters were used under different conditions, as all the U.K. helicopter accidents took place under broadly similar conditions on training or cross country flights and many of the American crashes must have occured under combat conditions.

The deaths of the 8 U.K. casualties killed in survivable crashes are of great interest; Table 9 shows why they did not survive, and suggests what might have been done to improve their chances.

ACCIDENTS AT SEA

5 of the 8 casualties were drowned in 3 crashes following mechanical failures over the sea. In the first accident 2 winchmen were regaining their seats after a winching exercise but were still not strapped in when the aircraft struck the water; one man happened to be supported by the forward bulkhead of the cabin at impact and he managed to get out and make his way to the surface. The other man was unrestrained at the back of the cabin; he was thrown around inside the cabin, and hit his head hard enough to daze him and prevent his escape. In the second accident 2 men from the cabin managed to escape although one of them was unconscious when he reached the surface, while 3 others were drowned. The men had to be able to move freely around the cabin to do their jobs, and so it happened that at the time of the accident they were not strapped in.

The pilot in the third accident had escaped from 3 previous ditchings; he managed to get out of the aircraft when it was 30 ft under water in spite of having a crush fracture of the spine, but the navigator went down with the aircraft. Divers found him outside the door, snagged by his dinghy pack; he was a bulky man (height 72 inches, weight 209 lbs) who had had difficulty with previous ditching drills. Bone marrow emboli were found histologically, suggesting that he might have had a spinal fracture which was overlooked at the gross autopsy.

The casualties in the first 2 accidents would have had a fair chance of surviving if they had been properly strapped in at the time of the accident - they died because the crash occured at a time when their duties required them to be unrestrained. The navigator in the third accident very nearly succeeded in escaping; it is possible that more intensive training until he was proficient in ditching drills and underwater escapes might have enabled him to save his life. There would have been no deaths in any of the 3 accidents if it had been possible to provide effective buoyancy to keep the helicopter itself afloat.

ACCIDENTS ON LAND

The other 3 accidents happened on land. In the first, a helicopter flew into high ground in the dark and the observer was thrown clear and knocked unconscious; the pilot was retained within the fuselage head downwards, and died of traumatic asphyxia although he had no major injury. In the second accident a helicopter crashed and burst into flame following a mid-air collision. The pilot was found just behind the wreckage of the cabin; death was attributed to burning and to multiple injuries. He might not have survived if there had been no fire, but in fact death was due to burning and his life might have been saved if fire fighters had been on the spot. These 2 accidents were in remote places far from rescue, but many accidents happen during take-off or landing, close to rescue facilities.

The helicopter in the third accident crashed on the runway after taking part in an air display, and although fire broke out the rescue team were in time to save the pilot; the co-pilot sustained lethal injuries while submarining feet first through his harness, and might have survived if his harness had been fitted with a crutch strap to prevent this. The case for crutch straps is reinforced by 3 other fatalities in non-survivable accidents, who also sustained lethal injuries submarining.

CONCLUSIONS

Strenuous efforts (References 3 and 4) are already being made to prevent accidents by reducing their main causes as suggested in Table 10 - by improving aircrew training to avoid "pilot error" by improving the mechanical reliability of the aircraft. Efforts are also being made to provide escape systems, to improve the crash-worthiness of helicopters and to provide better restraining harness and personal protection.

As well as these general measures, Table 11 shows this series emphasises the need for efficient buoyancy devices for helicopters used at sea, for using full restraining harnesses fitted with crutch straps, and for the best possible early rescue facilities.

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Table 1

CIVIL HELICOPTER CRASHES IN U.K.

Crashes recorded by Civil Aviation Authority 1958-74	132
Fatal crashes 1958-74	13 (10%)
Fatal crashes 1974-75	3
TOTAL FATAL CRASHES 1958-75	16
Crashes investigated by Department	8 (50%)

Table 2

FATAL HELICOPTER ACCIDENTS IN U.K. INVESTIGATED BY DEPARTMENT 1956-75

Royal Air Force	9
Civilian	8
Royal Navy	7
Army	3
TOTAL	27

Table 3

ATTRIBUTED CAUSE OF ACCIDENT

PROVEN MECHANICAL FAILURE IN AIR		11 (41%)
APPARENT "PILOT ERROR"		11 (41%)
Hit ground after manoeuvre	4	
Mid-air collison	3	
Hit ground at night	2	
Hit ground in bad weather	2	
CAUSE OF ACCIDENT UNDETERMIND		5 (19%)
Training Flight	2	
Crashed after take-off	1	
Crashed on Cross Country Flight	2	

Table 4

SURVIVORS IN UK FATAL HELICOPTER CRASHES

	CRASHES	MEN	DEATHS	SURVIVORS (% Survival)	
NON SURVIVABLE CRASHES	21	48	44	4	(8%)
SURVIVABLE CRASHES	6 (25%)	19	8	11	(58%)
On Land	4	6	3	3	(50%)
At Sea	3	13	5	8	(62%)
TOTAL CRASHES	27	67	52	15	(22%)

Table 5

FATE OF FATALITIES

	CRUSHED IN FUSELAGE	RETAINED UNCRUSHED	THROWN CLEAR	TOTAL DEATHS
Royal Air Force	62%	24%	14%	21
Royal Navy	12%	88%	-	16
Civilian	55%	18%	27%	11
Army	50%	25%	25%	4
				52

Table 6

CAUSE OF DEATH

	Multiple Injuries	Head Injuries	CVS Injuries	Drowning	Burning	Asphyxia	Total Deaths
Royal Air Force	95%		5%				21
Royal Navy	31%	25%	6%	31%		6%	16
Civilian	82%	9%	9%				11
Army	50%	25%			25%		4
							52

Table 7

TIMING OF FATAL INJURIES

	AT IMPACT	POST IMPACT			
		Drowning	Burning	Other	Total
Royal Navy Crashes	63%	31%		6%	16
Other UK Crashes	97%		3%		36
	87%	10%	2%	2%	52
U.S. Army 1970-71 (After Miller & Sand 1973)	50%	15%	34%	1%	246

Table 8

OCCURENCE OF POST-MORTEM FIRE IN UK FATAL CRASHES

	FIRE	NO FIRE	UNCERTAIN
NON-SURVIVABLE CRASHES	14 (67%)	6 (29%)	1 (5%)
SURVIVABLE CRASHES	2 (33%)	4 (67%)	-
	16 (59%)	10 (37%)	1 (4%)

Table 9

DEATHS IN SURVIVABLE ACCIDENTS

	CRASH	DEATHS	CAUSE	REMEDY
CRASHES AT SEA	No 1	1	Unrestrained at impact	1. BUOYANCY 2. TRAINING
	No 2	3	Unrestrained at impact	
	No 3	1	Equipment snagged: Bulky Man: Difficulty with escape drills.	
		5	FAILED TO ESCAPE: DROWNED.	
CRASHES ON LAND	No 1	1	Traumatic asphyxia	EARLY RESCUE
	No 2	1	Burning	
	No 3	1	Submarining injuries	CRUTCH STRAP
		3		

Table 10

GENERAL ACTION TO SAVE LIVES IN THE FUTURE

A. PREVENT CAUSES By reducing:-

- i) "Pilot Error" by training harder
- ii) Mechanical failures by improved reliability

B. REDUCE FATAL INJURIES By improving:-

- i) Escape systems and training
- ii) Crash worthiness of aircraft
- iii) Restraint systems, and their use
- iv) Personal protection equipment

Table 11.

THINGS WHICH WOULD HAVE PREVENTED DEATHS IN SURVIVABLE ACCIDENTS IN THIS SERIES

		LIVES THAT MIGHT HAVE BEEN SAVED
i)	EFFECTIVE BUOYANCY	5 (63%)
ii)	EARLY RESCUE	2 (25%)
iii)	CRUTCH STRAPS	1 (13%)
		8

DISCUSSION

KNAPP: Which is worse, a low level of blood alcohol as a result of recent intake or the "hangover" resulting from intake in the more distant past?

BALFOUR: I wish I could answer your question definitely, but obviously it all depends on the lowness of the alcohol level as against the severity of the hangover and how distant the past drinking was. I suspect, however, that if one compared two people whose ability was apparently impaired to about the same degree, as measured by a few simple tests, then testing in greater depth might show that the person with the hangover was in fact the more severely impaired. The effects of recent drinking might well be limited to the pharmacologic effects of alcohol, whereas many other factors would be likely to contribute to the hangover, such as trace impurities in the drinks, fatigue, late hours, smoking and lack of fresh air, and irregular eating, and their cumulative effects would affect many systems of the body and be a much worse over-all handicap than a recent drink or two.

FUCHS: In 1972, an ASMP Specialists' Meeting was held at Glasgow on "The Use of Medication and Drugs in Flying Personnel." This meeting answered the questions of alcohol intake as related to flying. For example, the GAF Regulations provide useful guidelines for the amount of alcohol permissible in a given time span in making the determination of whether or not to fly. It is recommended that all those interested obtain a copy of that Conference Proceedings.

KNAPP: Published U. S. Army accident statistics for helicopters represent noncombat data. This includes burn data. Since the advent of the crashworthy fuel systems, there has been only one fire fatality in aircraft equipped with this system. The one fatality was caused by a known flaw in the design of the system, but the victim was rendered unconscious by impact forces and thus could not escape.

BALFOUR: Firstly, thank you very much for this information. Secondly, may I take the opportunity of adding that I have just been told that the Royal Navy people have found that since they started their "Dunker" training simulating a helicopter falling into the sea, their aircrew are not only better able to escape from crashes at sea but also are now confident of their ability to do so.

ROENTGENOGRAPHIC EVALUATION IN FATAL AIRCRAFT ACCIDENTS*

by

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SUMMARY

The roentgenogram has great value in the investigation of fatal aircraft accidents. The entire spectrum of the accident can be evaluated with this modality magnifying and *enhancing the information available. Calibration of the roentgenogram for use in the* investigation of a fatal aircraft accident will provide even more useful and factual data. More complete use of the roentgenogram in these investigations should be mandatory.

INTRODUCTION

In the investigation of fatal aircraft accidents, the need for and value of factual information is great. The use of the roentgenogram as a tool for studying the environment of a fatal aircraft accident enables the investigating team to extract some measure of factual data. Considerable time is saved by thorough use of this modality in the investigation of the post-accident situation.

The roentgenogram is a most dynamic form of evaluation. The findings on the roentgenogram are consistently accurate, reliable, and reproducible. They do not readily lend themselves to errors of individual interpretation and description, as do some other types of findings. The roentgenogram provides rapid, complete review of trauma on the human body, demonstrating aberrations of the bony structures and soft tissues. In addition, its complete use in the full scope of the investigation of the fatal aircraft accident is of value. Roentgenologic findings can be quickly reviewed, presented to persons involved in the accident investigation, and easily stored for documentation and further study regardless of the disposition of the human remains or other materials studied.

The roentgenogram has a vast potential in the evaluation of fatal aircraft accidents and should be an integral part of these investigations.

THE ROENTGENOGRAM AS USED IN THE INVESTIGATION OF DEATH

The roentgenogram has been found to be quite useful in forensic medicine. It is often employed in identification of human remains as well as in determining the cause of death (1). Human remains, clothing, and personal articles can be scanned with fluoroscopy, which quickly and accurately localizes areas of interest for permanent roentgenographic documentation.

The estimation of age, sex, race, and living stature is often made through the use of the roentgenogram.

In identification of human remains, dental and skeletal roentgenograms are used. For example, dental roentgenograms are compared with previous studies of the teeth, which is a means of identification often as accurate as fingerprinting. Skeletal roentgenograms are also compared with previous x-ray studies in an attempt to demonstrate similar appearance, sex, pre-existing disease, age, and living stature.

In determining the cause of death, the roentgenogram may demonstrate foreign bodies or metallic fragments that shed light on the instrument of death or the cause of the crash. These objects are often obscured in the usual autopsy, hidden in bones, joint spaces, and soft tissues not accessible to a detailed examination.

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*The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

OBTAINING THE ROENTGENOGRAM IN THE POST-ACCIDENT SITUATION

The difficulties encountered in obtaining roentgenograms in the post-accident period relate to the general unsightliness and odor of human remains. Lack of continuity of human parts and other signs of severe trauma such as burns and decapitation may cause reluctance in persons not accustomed to dealing with autopsy materials. A general lack of understanding of the significant information available from a dead person may result in difficulties, further reducing the chances for an optimal study and findings.

It is to be remembered that the usual x-ray department of a hospital does not provide for back-door entry and exit with human remains. Therefore, the well-being of patients in waiting rooms should be considered, and discretion should be used in moving human remains to and from examination rooms. They should be well draped and out of sight except during the roentgenographic examination. Arrangements should be made at the convenience of the x-ray department so as to obtain high-quality roentgenograms. If fluoroscopy is not necessary, portable roentgenographing in the autopsy suite may be sufficient.

Any potential problem is obviated by prior planning and consultation by the pathologist or the flight surgeon with the appropriate member of the x-ray department. The pride of technicians in their work is challenged by these unusual technical problems, and explanation of the value and need for these studies should be discussed with them. The pathologist should be in attendance during the x-ray study to point out areas of interest and suggest different views or oblique angles. Following the study, the roentgenologist should be consulted so that he may review the roentgenograms, point out technical artifacts, and provide the full benefit of his experience in interpreting the findings.

USE OF THE ROENTGENOGRAM IN THE PATHOLOGIC EXAMINATION

Roentgenograms should be obtained on all victims of the aircraft accident. These should be complete views of all parts of the body and all masses of tissue. Frontal and lateral projections should be obtained. Roentgenograms of good quality should be obtained on all autopsy materials. This allows for documentation of all findings prior to disruption of the tissue in the autopsy or in preparation of microslides.

The roentgenogram is the pure form of the gross pathologic state and assists the pathologist in many ways. Differentiating injuries from mechanical from those caused by other forms of physical energy may be indicated at a glance. Blunt versus sharp injury can be distinguished. The absence of bony or soft tissues will be revealed. Bones from other victims and from animals can be separated. Fractures, their location, and their angulation can be accurately recorded. Nondisplaced fractures that would otherwise go unnoticed are found. Pre-existing injuries, disease, and congenital lesions are discovered. The presence of a pneumothorax, pneumocranium, pneumoperitoneum, or interstitial emphysema may be easily documented prior to opening these areas at autopsy. Soft tissue abnormalities such as lacerations, edema, and small puncture sites may be detected and recorded. The presence of portions of the abdominal contents in the thorax indicates severe abdominal trauma. Roentgenograms can assist with categorization and identification of most gross findings.

Interior areas that are difficult for the pathologist to visualize adequately, such as the face, neck, vertebral column, and extremities can be reviewed rapidly and efficiently in the roentgenogram. Vertebral fractures may be easily distinguished as to type: shearing (Fig. 1), compression, or the Chance type (2, 3).

Recently ingested medication may be seen on the roentgenogram, giving insight into the personal habits or pre-existing diseases of the victim. Facial fractures and abnormalities of the sinuses may be seen.

The roentgenogram can assist the pathologist in synthesizing the findings at autopsy. A projectile identified in the skull shows its path by fragmentation of bone, allowing the angle of the missile to be determined. The demonstration of an entrance wound in a single fragment of the skull aids in its differentiation from skull fractures secondary to heat, as in a fire (Fig. 2).

The roentgenogram may direct the pathologist to areas of concern that were not considered initially, stimulating deeper study of a particular aspect of the autopsy. In the investigation of the Comet 4B aircraft crash (4), the finding of numerous small metallic fragments on a chest roentgenogram would have provided suspicion of explosive discharge aboard the aircraft earlier in the course of the evaluation.

Other examples of the value of the roentgenogram in the pathologic evaluation in the post-accident investigation could be cited. The few given here, however, point out and demonstrate the value of the roentgenographic study of every victim in a fatal aircraft accident, to aid the pathologist in the evaluation of findings and to speed up the process of this evaluation.

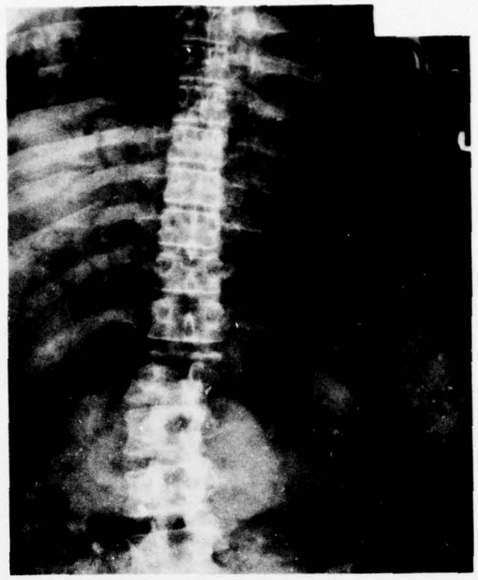

Fig. 1. Shearing fracture.
(AFIP Neg. 73-4261-8.)

Fig. 2. Artifactual blow-out fracture occurring in a fire.
(AFIP Neg. 62-4394-1.)

USE OF THE ROENTGENOGRAM IN THE EVALUATION OF THE DYNAMICS OF FATAL AIRCRAFT ACCIDENTS

Just as the structural derangements of an aircraft are used to determine forces generated in accidents, the aberrations of the bony structures and soft tissues as captured by the roentgenogram will yield the same kinds of information. The direction and magnitude of the forces can be determined. A fracture of the long bones, when triangular, has its base in the direction from which the force was incurred (1). The magnitude of the force can be suggested by the degree of displacement of the fragments of bone and associated injury of soft tissue. Correlation of this information with other aspects of the aircraft-accident investigation is essential to the full investigatory effort, as suggested by McMeekin (2, 5).

Further information can be obtained from roentgenograms. Who was in control of the aircraft at the time of the accident may be determined. Krefft (6) indicated that the person in control of the aircraft would have characteristic injuries caused by the controls that could be accurately determined and documented by roentgenograms of the hands and feet, as exemplified in our Figures 3 and 4.

Fig. 3. Roentgenogram of hand at the controls.
(AFIP Neg. 73-4261-5.)

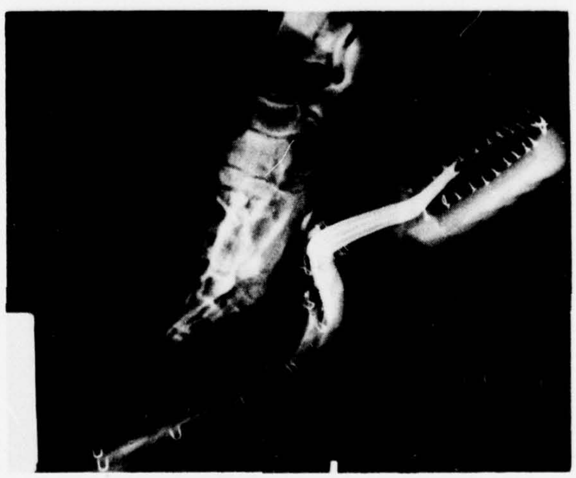

Fig. 4. Roentgenogram of foot on a rudder pedal.
(AFIP Neg. 73-4261-4.)

Similar evidence of who was at the controls of the aircraft was described by Dummit and Reid (7), who demonstrated comminuted fractures of the tibia and fibula caused by attempts to correct the attitude of the aircraft. The roentgenogram provides information in this characteristic injury. An indication of direction and magnitude of the forces generated in this injury are indicated in Figure 5.

Simson (8) demonstrated the use of the roentgenogram and pointed out its value in evaluating the human factors in a fatal aircraft accident.

USE OF THE ROENTGENOGRAM IN OTHER ASPECTS OF THE INVESTIGATION OF FATAL AIRCRAFT ACCIDENTS

The roentgenogram is valuable in extracting evidence from other aspects of the environment of the fatal accident than human remains. A roentgenogram taken of the seat cushion in the crash of the Comet 4B in 1967 (4) indicated metallic fragments similar to those found in the chest roentgenogram of a victim. This suggested an explosion and again points out the value of the roentgenogram as a tool in the study of the environment of an aviation accident. Further uses include roentgenograms taken of underlying soil samples in an effort to locate aircraft parts and human remains (Figs. 6 and 7).

When large volumes of soil are required to be evaluated, fluoroscopy may be used to eliminate time-consuming activities such as sifting for fragments of the crash victims or aircraft.

The use of the roentgenogram is limited only by the imagination of the investigating team, and any item of question should be studied with this tool.

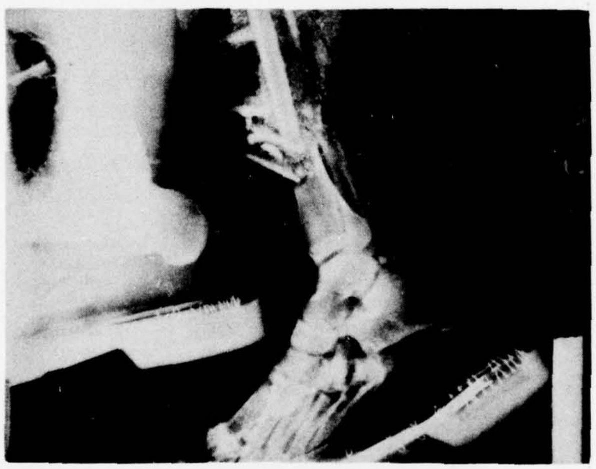

Fig. 5. Roentgenogram showing extensive fractures of the tibia and fibula. (AFIP Neg. 73-4261-4.)

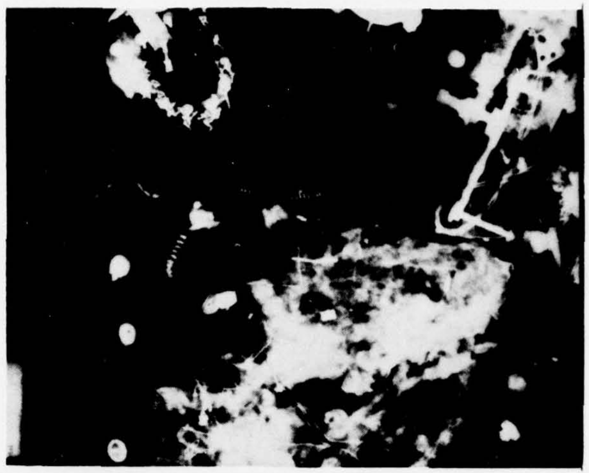

Fig. 6. Roentgenogram of the soil from the crash site containing wreckage. (AFIP Neg. 73-7381-9.)

Fig. 7. Roentgenogram of a victim's foot found in the soil shown in Figure 6. (AFIP Neg. 73-7381-10.)

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DISCUSSION

KNAPP: Roentgenograms have great use in both fatal and nonfatal accidents if the views can be oriented to show direction of force and if the flight surgeon and the radiologist can agree that there is more to learn from x-ray films than just presence or absence of injury. Unfortunately, if the victim survives, no further utilization of the x-ray film to evaluate magnitude and direction of force takes place.

MOSBY: At least, the appropriate x-ray films are available, which is not always the case in a fatal aircraft accident. I do agree that there is a great deal of information in the roentgenogram that is not interpretable because of the lack of correlation of this modality to the aviation environment.

COOKE: Will modern techniques of taking roentgenograms of soft tissue have a role in this method of evaluation?

MOSBY: Yes. They are only extensions of regular roentgenograms, however, in providing a "microscopic" view of the findings. The low mA, long exposure time may be useful in finding small radiodense fragments of importance in a particular fatal aircraft accident, as it is in mammography. The more sophisticated studies such as sonography and computerized axial tomography are very expensive and new, which will limit their availability for some time.

VOURSLUIJS: I have not found a clear definition of "pilot error." Would you comment on the meaning of this term?

McMEEKIN: The use of the term "pilot error" depends on where you believe the blame for the accident lies. A manufacturer may believe that pilot error accounts for 100% of all accidents; we, on the other hand, feel that there is no such thing as pilot error. If you pursue further into accidents that have been blamed on pilot error, you can always find a defect in training, supervision, or some other factor that initiated the fatal chain of events. Even mechanical failures, when probed in depth, can be traced to the human element involved in defective manufacture, inadequate inspection, or improper installation. Under some circumstances, however, particularly where you are trying to evaluate situations in which the pilots were a link in the fatal chain of events, it is useful to be able to identify those cases and to be certain that all of the related cases are included in the study. For this limited function, some category, whether called "pilot error" or "human element" or some other term, is necessary.

PARTICIPANT: We have given up the term "pilot error" because we feel that this seems to mask the cause of the accident. There is a tendency to make "pilot error" a grab bag to throw everything into when no other cause is found. It certainly engenders a great deal of hostility among the pilot population, and we think it's a rather destructive and negative term. We take the view that in any accident there is always a human component, whether in design, maintenance, operation, or some other area. When the main spar of a wing fails, it may be the result of poor design, poor maintenance, or improper operation. In each of those phases, it's the human element that is important. It's the human element that you have to get at in order to prevent the recurrence. For these reasons we stay away from the term "pilot error."

BLACKBURN: Injuries similar to those reported by Dr. Ewing have been found following high-speed ejections and high-shock parachute openings, particularly parachutes with ballistic spreaders. Are these injury types the same?

EWING: We have been conducting a joint study--the Naval Aerospace Detachment in New Orleans and the National Parachute Test Range at El Centro. This study is designed to determine the inertial accelerations with instrumentation packages mounted on the head and first thoracic vertebra of human volunteers. Various parachute forces, including riser forces, are being determined. In one particular case, a person using a ballistic-spreader-gun parachute in a drop from an aircraft at approximately 10,000 feet received a deceleration produced by the parachute at the time of parachute opening of approximately 20 G. We were not able to determine the head acceleration because his head flexed so far forward that the instrumentation package at the mouth smashed the altimeter mounted on the reserve parachute. It appears that the effect on the man was either concussion or some disruption of cerebral function for at least 20 seconds.

BLACKBURN: This type of data will prove very useful. The U. S. Navy is developing a system for survival in helicopter emergencies by which the rotor blades and tail cone are blown off so that parachutes can be used to bring down the helicopter and its occupants to a survivable impact landing. Development of this system is almost complete.

McMEEKIN: A large number of participants have posed questions relating to cardiovascular disease. The first of these is, "Do you believe that there is actually more coronary heart disease than has been supposed?" From a pathologist's viewpoint and in terms of accident causation, we have recently begun to suspect that there is actually a great deal more cardiovascular disease contributing to the causes of aircraft accidents than we had previously believed. In the 1960's, especially, we almost bent over backwards to avoid calling a controversial lesion in the heart a factor in the accident. At a time when passengers were being led to believe that the sky was full of drunk pilots and pilots who were fugitives from the coronary-care wards, there seemed little need to reinforce that fear. In retrospect, we think there were more coronary-disease factors in these accidents than were reported and that the failure to report more of those cases has led to a false sense of security.

A major factor that hampers evaluation of this problem is that autopsy protocols have been inadequate and incomplete. In many cases, the local authorities have performed only an external examination of the body and then signed the cause of death as "airplane accident." These are the cases in which cardiovascular disease was not even considered and no examination was performed. On the other hand, we have cases in which there has been massive destruction of the body with avulsion of many body parts and there is no heart present. In this event it would be impossible to diagnose coronary artery disease even if it were present and a factor in the accident. These two categories account for approximately 50% of all aircraft-accident fatalities. There is certainly potential in these cases for having cardiovascular disease as a causative factor.

Another factor to be considered is the inadequacy of our techniques for detecting acute cardiac events. If someone driving an automobile should suffer an acute myocardial infarction, the chances are that he will be able to pull over to the side of the road and will not have an accident. If a pilot has a similar problem, "the side of the road" may be 15 minutes or more away, and the potential for an accident is greater. Even if this were not the case, the pathologic changes we are able to detect usually do not occur for a minimum of 2 hours.

COOKE: I am not a pathologist, but I spend a lot of time talking about this problem to pathologists. The pathologist is the one, in the end, who determines whether my type of work is effective or not. There is increasing concern in all of our countries now about ischemic heart disease, and I think there is a trend towards more restrictive standards for medical licensure, both service and civilian. This has been based on a comparatively small number of accidents in which there has been clear evidence that ischemic heart disease has played a major factor. In some cases there is gross narrowing of the lumens of the coronary arteries, but can you see any future method by which you will be able to tell whether there had been just the beginning of an infarction or an arrhythmia that resulted in the accident?

ROUND-TABLE DISCUSSION (continued)

WOOTON: I am sure that you agree that the human body is the most complex chemical factory there is. Any action that occurs in the body results from a chemical chain reaction. I feel that a lot of progress could be made in histochemistry in the search for diagnostic changes such as can occur in a myocardial infarct, rather than having to look for gross changes, which will not develop in the short time period we are concerned with in aircraft accidents.

BALFOUR: I'm sure that as time goes on, we'll get better methods for studying the chemical and histopathologic factors, including enzyme tests for coronary disease, because these are universal medical problems not confined solely to accident investigation.

McMEEKIN: I think that it will be very difficult to detect cardiac arrhythmias by autopsy procedures. Some progress may come from examination at the molecular level, but to my knowledge very little work has been done in this area. The problem, as I pointed out, is that death occurs very rapidly. Even if the person didn't die from his acute coronary event, the subsequent traumatic injuries certainly would appear to the examining pathologist to have been sufficient to be the cause of death. We may be talking in terms of minutes or seconds in trying to distinguish between cardiac changes and traumatic changes. If this is the case, we may not be able to answer the question at all. I think this is a very serious problem and am opposed to relaxation of the medical standards. The good safety record we have in aviation is, in part, the result of the hard-nosed attitude we have taken in establishing medical standards. The fact that we have not been able to positively identify these cases does not justify relaxation of the standards and waiting to see whether we have more fatalities. Although the pilot population is highly motivated to return to flying duty following diagnosis of various medical problems, I am not convinced that the medical standards should be changed in the face of common sense. This is more a problem in the area of workmen's compensation and should be dealt with by insurance rather than by changing the rules. I am sure that we are all very sympathetic when an aviator says "I want to go back to work," but I do not believe that we are protecting his best interests nor the interest of aviation safety by relaxing the medical standards.

EWING: In my experience, the military is able to exert greater control over medical standards than is the civilian community. I know of the case of a civilian pilot, aged 60, with severe partially controlled diabetes who had had at least six previous coronary occlusions verified by electrocardiograms and who was given a license to fly his private plane. The only restrictions were that he could fly only over his own ranch and only below 5,000 feet.

McMEEKIN: There are cases of commercial airline pilots who have received waivers and been allowed to return to flying with a diagnosis of Parkinson's disease. I would hope that you agree that this is too much relaxation of the medical standards.

GRABAREK: Today we usually depend on the well-known standard methods of cardiologic examination in aviation medicine, and it is also well known that these are sometimes insufficient. Most probably the rate of "silent" asymptomatic coronary illness is much higher than we suppose, as we have learned from pathologic studies. Echocardiography is one new noninvasive clinical cardiologic measurement. Are there other practical noninvasive methods for cardiologic examination? Did I understand correctly that the USAF seriously intends to introduce an annual cardiologic examination of pilots by coronary angiography?

GILLINGHAM: The USAF School of Aerospace Medicine is continuing to develop its electrocardiogram repository, which is used for an epidemiologic study of cardiac disease in the USAF pilots. There has been considerably more emphasis recently on cardiac catheterization to rule out coronary disease, but this is not a routine procedure at this time.

McMEEKIN: The problems we have been discussing are all very serious ones in that they directly affect our military missions. The over-all impact is much greater, however, since the inevitable answers will affect everyone, not just the aviation community. I certainly hope that these presentations and the discussions that followed have stimulated you to want to begin working even harder to find the solutions.

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14. Abstract

This volume contains the papers, discussions and a Technical Evaluation Report of the ASMP Specialists' Meeting held in Copenhagen, Denmark, 5–9 April 1976.

Three papers describe the organization and early development of aviation pathology and its applications to aircraft-accident investigation in the United States, Germany and France. These are followed by presentations on legal problems, including the international aspects of determination of jurisdiction to investigate aircraft accidents and to perform special procedures such as screening techniques in identification, correlation of biorhythmic criticality, and roentgenographic evaluation that have generated significant interest among investigators in recent years. Interpretation of toxicologic analyses, the significance of specific injuries, and investigation of accidents involving specialized types of aircraft such as helicopters and agricultural aircraft were also discussed.

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160 pages

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